Albert V. Baez

innovation in science education — world-wide

The Unesco Press

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Preface

The purpose of the present work is to promote improvements in science education—world-wide, but particularly in developing countries. After reviewing the present situation and the directions in which improvements might be sought, it describes the lessons learnt from some recent efforts to improve science education, analyses some promising trends, discusses areas for priority action and proposes some strategies for change. It is natural, therefore, that the book should be sponsored by Unesco which has a responsibility to assist its Member States in the development and improvement of their science education programmes at all levels.

As early as 1964 the United Nations Advisory Committee on the Application of Science and Technology to Development (ACAST) had indicated an interest in the improvement of science education with special reference to developing countries. ACAST commissioned two specially prepared papers, by L. J. Lewis *et al.* [1][1] and Albert V. Baez [2] respectively. In its first report on science education [3] ACAST recommended, *inter alia,* that a working party be convened under the joint sponsorship of ACAST and Unesco to report on the content and methods of secondary and pre-secondary science education as a basis for long-term action in this field. This report, prepared by J. Arthur Campbell, was discussed at a subsequent meeting of ACAST in December of 1969 and one outcome was a proposal from the United Nations Office of Science and Technology that Unesco should arrange to produce a book for a wider audience than that reached by the report. For this purpose, Unesco called on Dr Albert V. Baez.

Dr Baez was born in Puebla (Mexico) in 1912. He has taught and undertaken research in physics at several universities in the United States as well as in Baghdad (Iraq). He was a member of the Physical Science Study Committee (PSSC) which in the late 1950s started a revolution as regards both the content and methods of physics teaching.

1. Figure in brackets refer to the Annotated Bibliography, page 237.

He has been a visiting professor at the Open University (United Kingdom). He is the author of research papers in physics and articles on science education as well as a physics textbook and science teaching films. Between 1961 and 1967 Dr Baez was Director of Unesco's Division of Science Teaching. He has since continued to be active on the international scene as a consultant on science education to the United Nations Office of Science and Technology. At present he is the Chairman of the Committee on the Teaching of Science of the International Council of Scientific Unions (ICSU).

His book is addressed to all those in a position to make an effective contribution to the improvement of science education —decision makers and other officials responsible for planning and/or supervising the science components of educational systems, members of teams working on the reform of science curricula, university and teacher training college staff responsible for the pre-service and in-service training of science teachers, leaders of science teachers' associations, school directors and teachers directly concerned with innovative changes in science education. It may also interest a wider audience—for instance, parents of schoolboys and schoolgirls and generally all those interested in contemporary educational issues.

The views expressed in the book are the responsibility of the author and do not necessarily reflect those of Unesco.

Contents

Introduction

To innovate means to make changes or to introduce something new. Many changes have been made in science education in the last fifteen years and some of them will be described in this book in order to stimulate further experimentation and improvement. Improvement, after all, is our long-range goal and, of course, not all innovations have produced improvements. We have something to learn from the failures as well as the successes of past attempts at innovation in science education.

In this review we will address ourselves to such basic questions as: What is the nature of the innovative process? How do you get started in innovation? What criteria do you use to determine whether innovations have led to improvement? I wish I could say we had found simple and definitive answers to these questions, but we have not done so, because they are difficult questions. We will, however, give examples showing how others have attempted to produce improvements through innovation.

There are many different categories of people who are in a position to make an effective contribution towards science education improvement. One group, including scientists, educators and individual classroom teachers, generates the innovative ideas. Another group, the designers, hopefully including some members of the first group plus specialists in the use of media, develops materials and programmes from these ideas. Finally, there is the small but influential group of people with the power to make decisions about funding and later to implement such activities by, for example, introducing them into the school systems. Without their support, the work of the innovators would never be implemented on a large scale.

In the early 1960s, scientists in the United States of America and later throughout the world played an important role in all three categories. They formed groups for innovation, sought the needed funds and actually promoted the use of their products in the schools. But as innovative projects began to proliferate, it was discovered that

other professionals could also make significant contributions to the process. These included specialists in what we now call educational technology, writers and producers of films and other audio-visual aids, a few psychologists, especially those with a bent towards the theory of learning and behavioural analysis, and (on a world-wide basis probably constituting the majority) practising teachers. In many cases it was found that teamwork was necessary to create a product that would be useful to teachers and students, so that the trials of materials on both these groups played a significant role in obtaining feedback for their improvement.

Improvement can operate in many ways, two of which are from the pre-university level upward or the university level downward. One could argue, therefore, that a start on improvement at either level would be beneficial. Historically, in fact, many recent activities have started at the pre-university level. I have decided to focus attention on innovative activities in pre-university science education in which, incidentally, some university scientists have participated. A good reason for starting here is that if science is taught properly at the pre-university levels, it may be hoped that students will progress through their university courses with a better understanding of science.

But there is a more pressing reason. The majority of children, especially in the developing countries, never go beyond primary school. Whatever they learn of the facts, principles, methods and spirit of science so as to cope with living in a world that is being revolutionized by science and technology, they have to learn in the primary school. It has been shown, fortunately, that improvement activities at the secondary level have also induced the creation of other projects both at the primary level and later at the university level. Emphasis on secondary school activities is justified by the fact that for many people, especially in developing countries, it represents the highest level of formal education they can ever aspire to. For these reasons I shall concentrate upon secondary school science curricula and related teacher education programmes.

The strong emphasis which will be given in later chapters to examples from developing countries does not, I hope, imply that the book will be devoid of interest in other countries because I believe that, as regards science education, even the most advanced countries have sectors which can be considered underdeveloped. I hope, therefore, that readers in even the most advanced countries will find some stimulating ideas applicable to their needs.

In a synoptic work of this kind it was impossible for me to avoid choosing many examples that reflect my background as a physicist and later as a member of the Unesco Secretariat. I hope that the weakness due to omissions is balanced by the strength that comes from personal involvement.

I wish to acknowledge the great help I received in writing this book from the Unesco Secretariat. I also wish to thank Paul

Kirkpatrick, Arthur Berman and David Cohen for patiently reading all or parts of it and making useful suggestions for improvements. Without the original encouragement of Guy Gresford of the United Nations, I would never have undertaken the task of writing it.

ALBERT V. BAEZ
July 1975

Part I
The nature, goals and status of science education—world-wide

Readers who know the importance of science and technology in modern society and are already convinced of the need for continuous innovation and improvement in science education may wish to go over Part I lightly and move on to Parts II and III where examples of trends and actual innovative projects are given. Part I may be of special interest to non-scientists who have responsibility for making decisions concerning the scientific component of general education.

1

The roles of science education in perspective

Developments in science and technology

The impact of science and technology on society

Anyone living in or near a modern city anywhere in the world will see, hear and touch a multitude of objects throughout the course of the day which demonstrate the extent to which life has been affected by modern science and technology, objects ranging from soap, safety razors, toothpaste, hot water and telephones to cars, buses and trains, objects in offices, factories, homes, restaurants and theatres. It would be easy to make a list several pages long of devices designed to save physical labour and to assist in communication, information gathering and storing, entertainment and transportation.

Even things made of natural materials like wood, wool or clay have felt the touch of modern power tools, paints or pigments. In search of natural things, we can drive toward the sea or the woods but bulldozers along the road remind us that with powerful machinery like this man has polluted the earth, the sky and the sea. A few years ago we could have said that the moon, at least, had not been touched by man's technology. Today, alas, man has left his footprints on its soft clean surface.

The real importance lies, of course, not in the effect of technology on physical objects but in the changes it has brought about in our life styles. Consider how it has affected the way you eat, drink, travel, work, play, sleep and make love. Think about technology and life and death—about how babies are born today and how old people die as compared to a hundred years ago. We do very few things which repeat precisely the behaviour patterns of our grand-parents. Key influences are science and technology, which have been

the most potent forces for social change in the history of man, even though what we now call science has been with us for less than three hundred years.

Distinctions between science and technology

Although they are intimately linked, science and technology differ. The natural sciences include astronomy, physics, chemistry, biology and the sciences of the earth and space. Mathematics is a special case, but whenever I refer to science education I shall implicitly include mathematics. Science is both the process and the product of investigation and research.

Since man is part of nature there are some sciences, like anthropology, psychology and the social sciences, which deal specifically with man. These will, for the most part, be beyond the scope of our discussion of science education except in so far as they enter into the integrative process which I will consider later. But man himself has created many things that did not exist in nature—the so-called man-made world. In many areas, including medicine, agriculture and engineering, for example, man has intervened in nature and created objects and phenomena which are man-made or modified. Among these is the process of education itself, so we will eventually be led to consider even the existence of a science of education.

The organized body of knowledge concerning the man-made world is called applied science. In both natural and applied sciences, therefore, the process involves research and the product is a set of ideas, theories and principles which man may organize in particular ways.

Using the above criteria, technology is not a science. It consists, rather, of the practical knowledge of what can be done and how. It is not a body of theoretically related laws and principles. Technology is characterized by techniques, devices, procedures, processes and materials. It is more a collection of practical information relevant to the task of getting something done.

Consider an example from agriculture. A large crop of vegetables is in danger of destruction by insects. Agricultural scientists have developed insecticides for the task at hand. The decision to spray the crops from an aeroplane is made by an agricultural engineer taking health, economic and environmental factors into account. The actual spraying is carried out by a technician—a specialist who knows how to load the insecticide, fly the plane and spray the crops. The totality of techniques, procedures and materials used constitute the technology of insecticide spraying from an aeroplane.

Now let us consider what motivates scientists and technologists. What drives the scientist, pure or applied, when he is acting as a scientist, is the longing to know and understand. The key word is

'curiosity'. Other characteristics of this spirit of inquiry include: a questioning of all things, a search for data and for relations that give them meaning, a demand for verification and a respect for logic. In other words, the principal activity of a scientist is research.

What drives the technologist, on the other hand, is the desire to translate ideas and plans into working realities. The key word is 'know-how'. His aim is to get things done—not necessarily to theorize about the devices and techniques used in the process. The ideas implemented by technologists are sometimes, but certainly not always, derived from science and the corresponding plans are often developed by engineers, about whom I will speak presently. It is interesting to note that science is undertaken by scientists but that advances in technology are not usually made by technologists or technicians.

Research and problem solving—two modes of action

Science and technology spring from two different but equally important activities. One is the search for knowledge and understanding, the second is the application of knowledge to satisfy human needs. That they are fundamentally different modes of activity is seldom recognized, with the result that the word science is sometimes used loosely and erroneously to describe both. By overlooking the importance of the means whereby knowledge is applied, it has been downgraded and not given sufficient importance in education.

Both the inquiry mode of the scientist and the design mode of the engineer have been responsible for the tremendous social impact of science and technology. But the innovative trends in science education to date have honoured and tried to infuse into general education only the spirit of science, almost completely neglecting the spirit of change through design which characterizes the creative aspects of engineering and which has revolutionized technology.

The design process

We are all called upon daily to solve problems. In doing so, whether we know it or not, we use a process which might be called design. We may, for example, have to find the best means of transportation to get to work so we decide, with our colleagues, to organize a car pool. The solution involved making decisions. Although it did not involve making drawings or blueprints, it is a simple example of the design process.

On a professional level, design is the activity associated with engineers such as those, for example, who have to plan and guide the construction of the extremely elaborate installations and machines needed to send a spacecraft into orbit or land a man on the moon.

The number of decisions that have to be made for such an operation is astronomical and may require computers for assistance in storage and retrieval of information and even in the logic of decision making.

However, the solution of even the simplest problems of our daily lives involving food, clothing and shelter requires the logic and decision making approach of the engineer. If decision making is so important then, should it not be dealt with in our education—even if most of our students will never become engineers?

Some of the science education innovators of the past decade felt so strongly about the need to infuse the spirit of inquiry into the educational process that they asserted that all children and students at all levels should have some taste of the inquiring activities of the scientist and hence developed special programmes and curricula for the purpose. Should we not, therefore, begin to devise educational activities that will infuse all of education with the spirit of change through design, so that all of us may learn how to make sound decisions in our lives?

This new aspect of design has been characterized in different ways, for example, 'Bringing into being something new and useful that has not existed previously' and 'The imaginative jump from present facts to future possibilities' [4]. The effect of design in this new and broader sense is to initiate change in man-made things. It is clear, therefore, that creativity is an important element in design and for that reason alone should be considered in future educational planning [5].

The role of the engineer

I have already said that it is the engineer who applies existing knowledge to the solution of problems. He is the designer who has to exercise creativity and to make recommendations based on value judgements. He has to generate a product for a client who has the power to make the final decisions on whether to accept his recommendations, but he can nevertheless exercise some social responsibility because he should base his recommendations not only on technical factors of engineering design but on other and equally important grounds, including economic, safety, aesthetic, legal, diplomatic, psychological and cultural factors.

Foecke says:

> To me this is the central point. If a problem involves no significant dimensions of this type . . . then it is not an engineering problem but a purely technical problem. [6]

Theodore von Karman once said: 'The scientist explores what is, the engineer creates what has not been.' This comparison emphasizes the

creative role of the engineer but the following definition puts the burden of making value judgements on him as well:

> The function of the scientist is to determine *what is*, of the technologist to determine *what can be*, and of the engineer to recommend *what should be*. Of course, the client retains the power to decide *what shall be*. [6]

It can be argued that the activities of the engineer do involve making recommendations based on value judgements, whereas the scientist in pursuit of knowledge for its own sake does not have to consider ethical and other criteria because his conclusions and discoveries are essentially neutral in terms of values.

However, because many people with scientific degrees are today working for clients such as the government who determine what problems they should be solving, they are earning their living essentially as engineers and not as scientists despite their Ph.D. degrees. No wonder, then, that the man in the street, viewing some of the horrors that have emerged from technology, blames the scientists for them. To the extent that these scientifically trained men are working as engineers, they do have the social responsibility to make recommendations based on humane and socially oriented considerations.

Implications of inquiry and decision making for science education

My purpose in trying to clarify the distinctions between science, technology and engineering has been to note that in the modern world, beset by social and economic problems, there will be continued need for professionals highly trained in these fields but, perhaps more important, that the modes of action associated with the inquiry of the scientist and the decision making and design process associated with the engineer are both worthy aims that should somehow infuse all of education.

I am not thinking narrowly of science education here. I would like to see new projects that lead children on, motivated not only by the spirit of science but also by a competence in the solution of problems—what might be called the 'spirit of change through design'.

But I am thinking even more broadly than that. I would like to see more activities of the kind associated with technology and engineering incorporated into general education even in the early grades and I would also like to see the concept of education broadened to include a sense of social responsibility for all.

I have noted that the ultimate and most powerful decision makers in industry and government, for example, are usually not scientists or engineers. I should like, therefore, to envision an

educational experience that might give them a lifelong motivation generated by the curiosity of the scientist, a feeling of concern for other people (based on conscience and compassion), the creativity of the engineer and the competence to get things done which is associated with the technologist.

How these four Cs can infuse the educational process is something about which I shall have more to say when I discuss interdisciplinary and integrated approaches to education. For the time being I hope I have made it clear that improving science education means much more than teaching the basic sciences for the sole purpose of producing more and better scientists for the future. This is necessary, but it is not sufficient. It even means more than trying to infuse the whole educational fabric with the spirit of inquiry—the goal of the science education reform movement of the 1960s. It really means searching for ways in which the spirit of science, social responsibility, creative design and competence can motivate the children and young adults of tomorrow—world-wide.

The interrelationships between science and society

What are the pressing problems of society?

Some of the worst problems of humanity have either been brought about or aggravated by science and technology. These and other problems will, nevertheless, require more and wiser use of the scientific and technological way of thinking—not less—and hence will demand improved education in science.

What are the long-range goals of mankind and how are they related to 'science'? Who has taken the trouble to state them? Philosophers, statesmen, humanists, mystics and churchmen have pondered the problem and produced a variety of goals ranging from broad humanistic aims for the over-all improvement of the lot of mankind to mystical and religious ideas concerning a better life to come after death, often reserved only for those who have been chosen in accordance with selection rules attributed to the will of a supernatural being.

I am not competent to discuss this subject in depth, but I do believe that science and technology have improved the lot of large numbers of human beings on this earth and that they will continue to do so if they are guided by properly motivated men. This will

occur, I believe, regardless of the great variations which exist among the creeds men live by.

For a meaningful life, men need to be free of the fear engendered by ignorance and superstition. They require food and shelter, health and jobs. In these areas, science and technology have already enriched men's lives in many ways. But, as I have noted above, science and technology have also been responsible for some of the world's most severe aches and pains and I would like to analyse these briefly.

I have chosen four areas which threaten all mankind with disaster. I call them the four Ps: population, pollution, poverty and pursuit of peace. They are intimately interrelated with one another and with science and technology. I recognize that many other topics could have been included such as ecological and environmental degradation, the energy crisis, famine and the exhaustion of natural resources, but we could easily subsume them into one of the four Ps. The exhaustion of natural resources, for example, is producing a global impoverishment which could be dealt with under poverty and environmental degradation could be dealt with as pollution.

How have science and society impinged on these problems?

Population

The first and probably the most important threat is overpopulation. In a few countries such as Sweden, Japan and the United States, population growth has been almost checked in the last few years, but for the world as a whole the population is doubling approximately every thirty-five years. The global population in 1974 was roughly 4.0 billion.[1] By the year 2006, it is expected to be 6.8 billion.

Seventy-five per cent of the world's inhabitants live in the developing countries and the greatest immediate increments are bound to take place there. The population of Asia, for example, was 1,720 million in 1961 and is expected to be 3,720 million by the year 2000 (Fig. 1).

What has made possible these spectacular increases in recent years? Briefly, advances in agricultural and health technologies resulting in death rates lower than birth rates.

During the 10,000 years of mankind's agricultural phase, minor improvements made possible a slow but distinctive growth in the world population at a rate somewhat less than 0.1 per cent per year. Around 1750 the agricultural revolution was in full swing and its effects,

1. One billion equals 1,000 million.

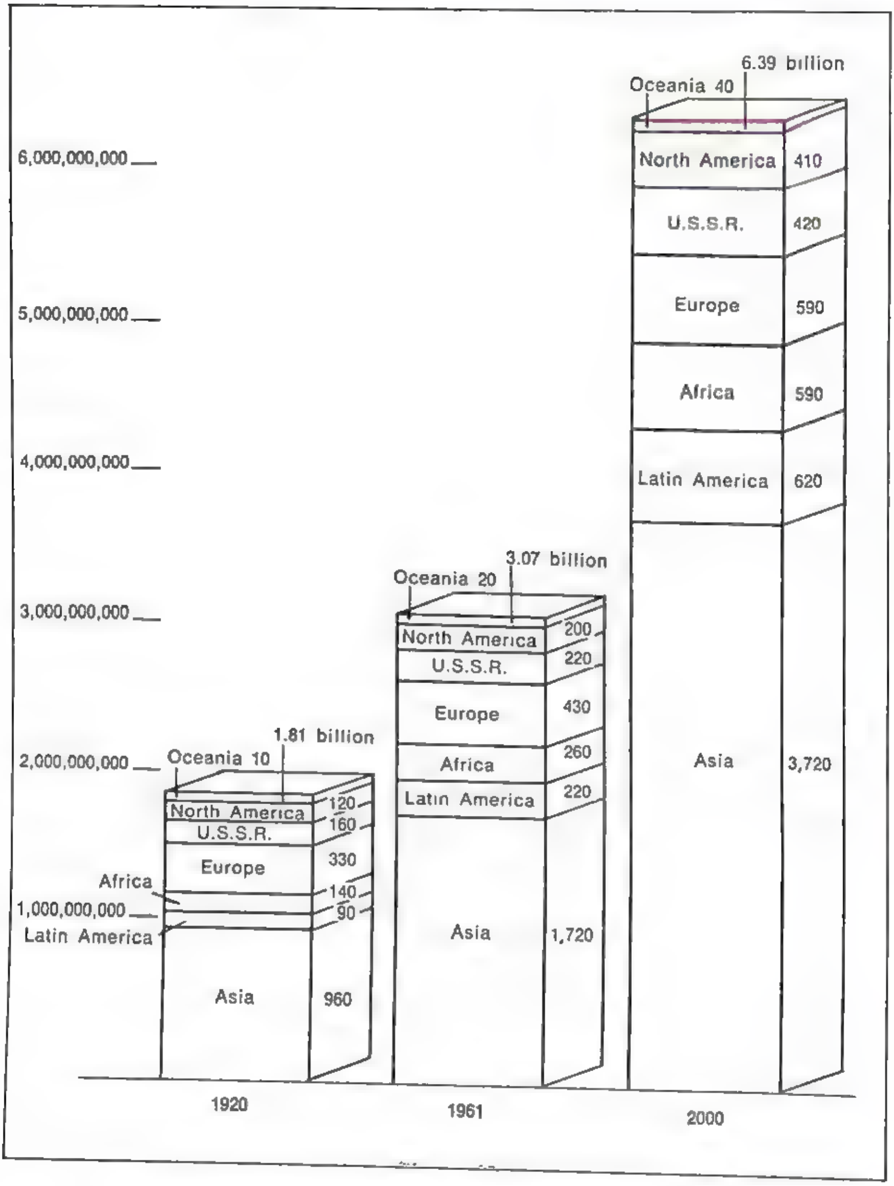

FIG. 1. World population and projection for year 2000 (courtesy of the Campaign to Check the Population Explosion, New York).

combined with those of the industrial revolution, were beginning to be felt; in particular, they produced both an increased birth rate and a decreased death rate so the growth curve exhibits a spectacular and exponential rise which, globally, is still in full swing despite recent efforts to curtail birth rates (Fig. 2). It took several million years for the world population to reach 2 billion in 1930, but a second 2 billion had been added by 1975.

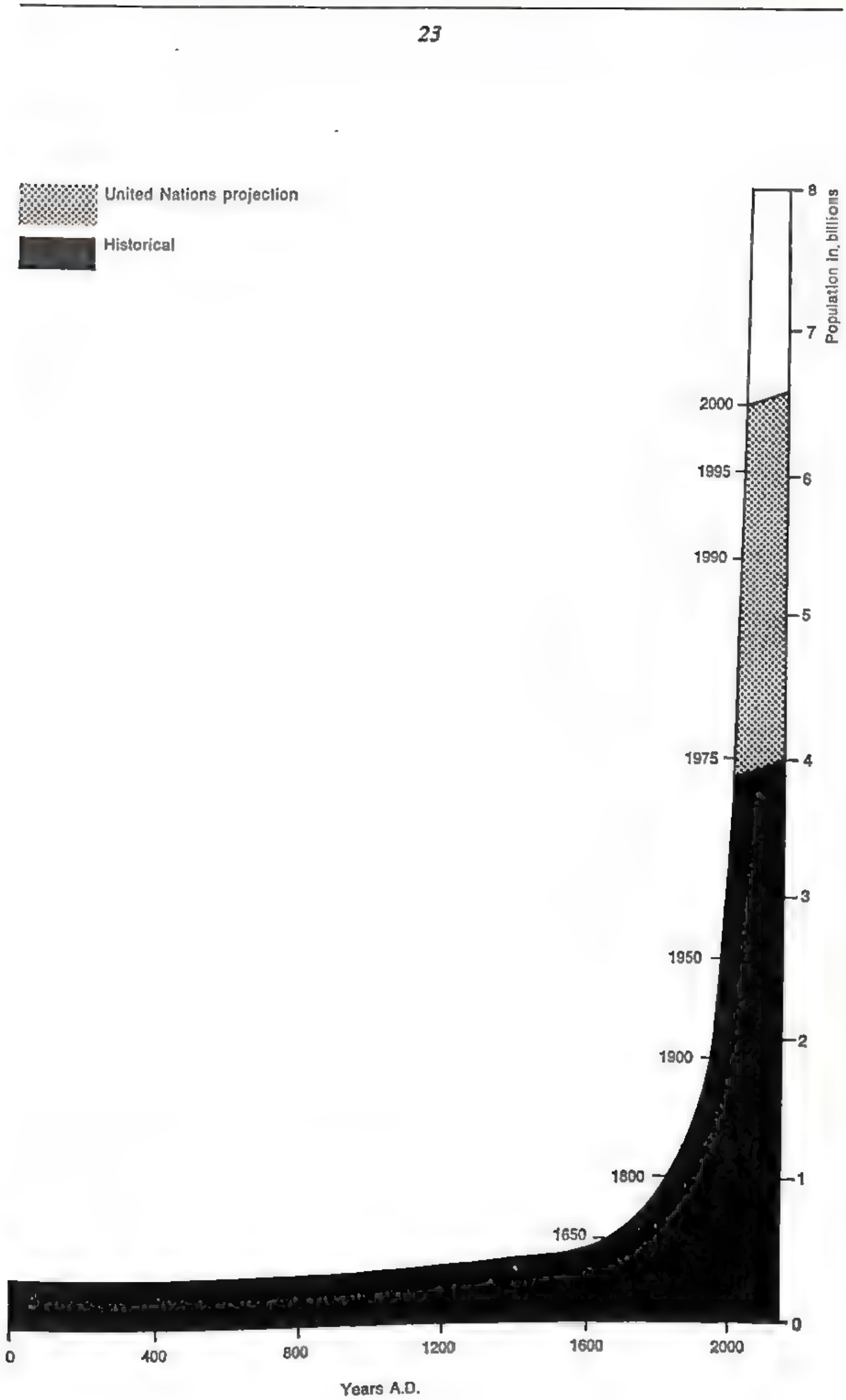

FIG. 2. Growth of world population.

The links with technology are clear. Adverse seasons ceased to produce famine due to improved food production and distribution. Epidemic diseases no longer decimated populations because nutritional standards had risen, and innovations in environmental sanitation and curative medicine produced steady declines in the annual death rates. It is both interesting and terrifying to consider that what was apparently a beneficial aspect of technology—the reduction of death due to disease and famine—has generated the overwhelming problem of overpopulation.

Pollution

An excess of people can cause depletion of natural resources, waste of energy, poverty and pollution. They are all interlinked and aggravated by overpopulation. The deterioration of the human environment, in particular, is a price we have had to pay for the advances in science and technology which led to industrialization.

As long as man was limited to what he could do with hand tools, his impact on the environment was negligible. But as soon as he had power tools and machinery to extract coal, oil and other fossil fuels from the earth in large quantities—some new power shovels used in strip mining can scoop up 200 tons in a single bite—he began to generate power and deplete natural resources at an unprecedented rate. Power is absolutely necessary to run an industrialized society, and it has been well said that power pollutes.

By now we have all read of some extreme cases of pollution such as rivers ablaze with oil burning on their surfaces, fish dying in polluted lakes, children having to leave school because of smog alerts, and the visibility in modern cities so reduced by pollution that, in the near future, automobiles in some cities may have to travel with their lights on in the middle of the day.

Perhaps the worst offender has been the automobile whose fumes, interacting chemically with the ozone in the atmosphere, produce the pall that hangs over all modern cities in both the advanced and the developing countries. Four hundred million pounds of finely powdered, toxic lead compounds spew from exhaust pipes in the United States alone each year. It has been estimated that the air contamination in Mexico City is occasionally 100 times an arbitrarily defined 'tolerable' level. Wherever the concentration of cars is large the danger exists. I remember almost suffocating on a murky summer evening on Al-Rashid Street in Baghdad as early as 1951.

The pollution crisis goes hand in hand with the energy crisis. In the advanced countries, the great number of amenities which make life so convenient are often responsible for an insatiable energy demand. Homes are heated and air-conditioned by energy consuming devices, many of them electrical. The United States in 1970 produced 1.5 trillion kilowatt hours of electricity—more than one-third of the

world production—and it is estimated that the demand will double every decade for the remainder of the century.

The affluent countries are the worst offenders. It has been estimated that the United States alone, whose population comprises only 6 per cent of the world's population, consumes 40 per cent of the earth's natural resources output. The rich invariably pollute more than the poor.

It is not surprising, therefore, that spokesmen for the developing countries are, for the moment, tolerant of a pollution problem that has not yet reached them with full force. They are more concerned with sheer existence than with pollution. They are worrying about starvation, not car fumes, and would rather see smoke coming out of a factory and men employed than no factory at all. Their attitude seems to be 'if it takes pollution to produce jobs and affluence, let's have some pollution'. One can sympathize with them, but they too will eventually have to recognize that we all live on a planet whose resources are finite and whose ecosystem is global.

It is estimated that in 100 years 80 per cent of the world's total resources of the petroleum family—crude oil, natural gas and others—will have been used up. Consider what this means. Coal and oil deposits took millions of years to develop from the vegetation that, utilizing photosynthesis, had absorbed energy from the sun over a period of millions of years, and man—the great predator and consumer—will have exhausted irretrievably practically all of these sources of energy in a total of about 1,500 years, a mere tick of the cosmic clock.

Other sources of energy, such as nuclear energy, are being developed, but it is certain that some of them will also generate pollution, not necessarily of the same kind as that produced by burning petrol or coal but probably just as dangerous, including nuclear radiation and heat in such large quantities as to endanger the continents by possible flooding due to the melting of the polar caps.

The developing countries aspire to industrialization, but it is clear that the global energy desires in the year 2000 will be impossible to satisfy in a world with twice the present population, and in which the developing countries will be trying to match the rate of energy consumption of the advanced countries. At present the rich nations consume more energy and pollute more. The poor people in affluent countries suffer the effects of pollution more than the rich. These inequities will give rise to social and economic tensions which will probably exceed anything that we know today.

Poverty

According to Harrison Brown, the overwhelming fact of the post-Second World War period is that human society has fissioned into two cultures, the rich and the poor. This is strikingly summarized in

a simple chart (Fig. 3) presented in the report of the Pearson Committee [7].

Before considering further the quantitative aspects of poverty, let us ask the question: What does it mean, in human terms, to be poor? It means malnutrition, protein deficiency with possible brain damage to children, corrosive hunger, famine, lack of medical care, poor health, disease, suffering, illiteracy, unemployment, apathy and despair.

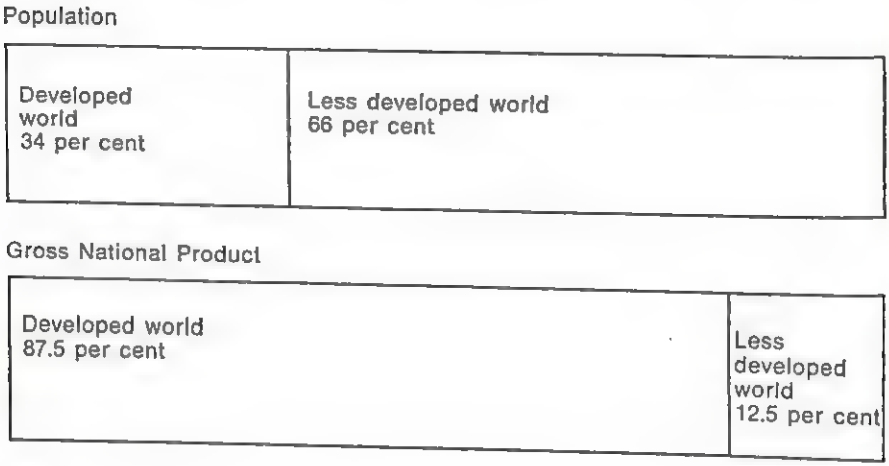

FIG. 3.

Even in the richest of countries there are pockets of poverty. In 1969 in the United States over 24 million people, roughly 10 per cent of the population, were living below the government-defined poverty level of $1,840 income per person per year. Of course, a poor person in the United States may seem rich in comparison with the 2,000 million or so poor who live in Asia, Africa and Latin America.

Here are some global figures for Gross National Product (GNP), one of the measures of national wealth. At one end of the scale only two countries, the United States and Sweden, have a GNP of over $4,000 *per capita*. Starting at the other end of the scale, there are fifty-six countries with a GNP *per capita* of up to $200. In between, the figures for a number of countries and corresponding GNP *per capita* are: forty-seven countries, $201–$400; sixteen countries, $401–$600; thirteen countries, $601–$800; ten countries, $801–$1,000; thirteen countries, $1,001–$1,700; and thirty-three countries, $1,701–$4,000 [8]. Another way of summarizing it is this: about two-thirds of the world's population have average annual earnings of only $125 per head while the remainder in the developed countries enjoy an average of $1,800 per head.

The relative wealth of the rich countries can also be expressed in terms of a key resource like steel. The relative figures would be about the same as for energy resources [9].

Table 1. A comparison of annual steel consumption in rich and poor countries

	Population in millions	Annual steel consumption in millions of metric tons	Annual steel consumption *per capita* in kg/person
The poorest	363	1.8	5
The poor	1,400	26	18
Intermediate	442	43	97
The rich	892	417	470

The chart makes it clear that a very small number of people in the rich countries consume a very large fraction of the total amount of steel used in the world.

The majority of the people in the world are poor and, furthermore, although the rich consume the world's resources at a much greater rate than the poor they are getting richer faster than the poor.

Over the period 1950–67, the less developed countries succeeded in increasing their GNP at an average annual rate of 4.8 per cent. But over the same period their population increased at 2.3 per cent per annum, reducing the average GNP increase per head to 2.4 per cent per annum. The industrially advanced countries experienced a slightly slower rate of growth but with a more stable population showed a net increase per head of 3.1 per cent per annum. The gap between the developed and the less developed world steadily widens.

It has been estimated that it would take 130 years for the poor to reach the levels of those who now consider themselves rich, but by then the rich would be approaching a *per capita* GNP of nearly a million dollars a year. There is obviously a strong link between overpopulation and poverty. It is due to the fact that food and other resources are not increasing at the same rate as population.

Although there have been very significant improvements in the world food production, it is still falling behind population growth despite all current national, bilateral and international efforts to reverse this trend. The world food production in 1966 was about the same as in 1965 but there were, by this time, 65 million more mouths to feed.

Robert McNamara has put it dramatically [10]:

> The gap between the rich and the poor nations is no longer a gap—it is a chasm.
>
> The consequences of rapid population growth, piled on top of an already oppressive poverty, must be grasped in all their concrete, painful reality.

The first consequence can be seen in the gaunt faces of hungry men.

One half of humanity is hungering at this very moment. There is less food per person on the planet today than there was 30 years ago in the midst of a worldwide depression.

Thousands of human beings will die today—as they do every day—of that hunger. They will either simply starve to death, or they will die because their diet was so inadequate that it cannot protect them from some easily preventable disease.

In summing up his own view, C. P. Snow says [11]:

The major catastrophe will happen before the end of the century. We shall, in the rich countries, be surrounded by a sea of famine, involving hundreds of millions of human beings.

Many millions of people in the poor countries are going to starve to death before our eyes—or, to complete the domestic picture, we shall see them doing so upon our television sets.

One hears young people asking for a cause. The cause is here. It is the biggest single cause in history.

It is the duty of all the rest of us, and perhaps most of all the generations which are going to live in what is now the future, to keep before the world its long-term fate. Peace. Food. No more people than the earth can take. That is the cause.

The pursuit of peace

It is ironically true that man throughout his long and tortured history has pursued peace mostly by waging war, and when an interval of peace was achieved it was often utilized to prepare for war—'in time of peace, prepare for war'. (The United States alone has spent over $1,000 billion ($10^{12}$) on military expenditures since the Second World War.)

It is also true that at this very moment a precarious peace exists which has been bought at the unbelievable expense of preparation for an all-out nuclear war which, both major powers concede, could wipe out a large percentage of the inhabitants of the northern hemisphere and leave the inhabitants of the southern hemisphere psychologically and technologically unprepared to tackle the immense job of reconstruction.

It is not possible here to consider the broad and unresolved problems of war and peace. The pursuit of peace arises simply as an illustration of the kinds of problems that pose a major threat to mankind—in this case of possible extinction—and because of its interactions with science, technology and education.

The founders of Unesco considered peace important enough to cite it in the very first sentence of the Constitution which reads: 'Since wars begin in the minds of men, it is in the minds of men that the defences of peace must be established.' This suggests at once that Unesco, the international organization devoted to education, science and culture, considers the pursuit of peace its long-range target.

Let me review very briefly some of the most recent examples of the impact of science and technology on warfare.

Since the days of the bow and arrow, the design and production of weapons has involved the ingenuity of technologists and the creativity of engineers. But the impact of modern industrialized society, geared to mass production of weapons and their use, was felt for the first time in the First World War. It spurred inventions that rapidly improved methods of communication (radio), transportation (the aeroplane), and reconnaissance (aerial photography) to cite just three examples. It also generated the development of huge cannons and chemical agents which were used for the first time in the most widespread, lethal and destructive war which had ever taken place. Science and technology had made devastation possible on an unprecedented scale.

Only twenty years later, however, the Second World War produced developments that dwarfed the activities of the First World War. The participation of scientists in warfare, which had paid off during the First World War, was accelerated and magnified during the Second World War, but a new dimension was added—the utilization of scientific knowledge which had just barely been discovered in the laboratory. The outstanding example of this was, of course, the development of the atomic bomb.

The financial, scientific, industrial and technological effort that was required to produce the first bomb exceeded any previous similar effort in history. It required a two-year crash programme that brought together the leading scientists of the world to help, and it cost $2 billion.

The atomic bomb represented a sizeable discontinuity in the history of war and possibly in the whole course of human events. A single bomb with the explosive power of 20,000 tons of TNT —'brighter than a thousand suns'—was something new and awesome indeed.

The dramatic destruction produced by the nuclear fission bombs that were dropped on Hiroshima and Nagasaki, killing a total of 152,000 people within a few minutes, seared the minds of men the way their lethal radiation had seared the bodies of their victims and became the awesome symbol of the tremendous power for destruction that man had generated. It was also probably responsible for a growing wave of distrust in science as an agent of peace.

Scientists participated on a large scale in the Second World War, but they were not following scientific pursuits. They were not, in other words, primarily motivated by a desire to understand phenomena in the natural or man-made worlds. They became, instead, highly creative designers and engineers.

Beside the development of the nuclear bombs, another activity that had a unique scientific input was the development of operations research which applied the systematic and quantitative approach of science to the problems of war. Its first important success was in

turning the tide of ship sinkings by German submarines in favour of the Allies. I will have more to say about this later because the ideas of systems analysis which grew out of it have since found widespread application in industry and may have a future impact in education.

The period of uneasy peace, called the Cold War, that followed the Second World War was characterized by suspicion among former war-time allies and a furious and extremely costly technological race that led to the development by the superpowers of the fusion or H-bomb—at least fifty times more powerful than the Hiroshima bomb—whose energy is measured in megatons of TNT. (The whole of the Second World War, incidentally, was fought with less than 3 megatons. Today a single H-bomb is the equivalent of 20 megatons.)

The need for sophisticated methods of delivering nuclear weapons led to another spectacular development, the orbiting earth satellite, the scientific theory for which had already existed for two hundred years. The Russian Sputnik was the pioneer, but it sparked a mad race for space supremacy which has cost the United States alone many billions of dollars. One measure of this activity is that in 1974 there were about 500 earth satellites orbiting the earth simultaneously. They are ostensibly used for scientific investigation, but it is obvious to the whole world that the technology can also be used for reconnaissance and rapid delivery of nuclear weapons—it takes less than 90 minutes for a low-altitude satellite to orbit round the earth.

Many scientists and other people believe that the ultimate folly would be the actual use of the nuclear bombs residing in rocket launching silos and in nuclear submarines, but is it not folly to waste the money, resources and talent needed to keep improving these weapons (which are still costing over $10 billion a year to maintain and increase in number) when such money, resources and talent might be used instead to solve the problems of overpopulation, pollution and poverty?

A group of scientists issued in 1970 what has been called the Menton statement [12]. It summarizes my own point of view succinctly:

> Throughout history there has been no human activity so universally condemned and so universally practiced as war, and research on ever more destructive weaponry and methods of warfare has been unremitting. Now that we have achieved the ultimate weapon and seen its potential, we have recoiled from its further use, but our fear has not kept us from filling our arsenals with enough nuclear warheads to wipe out all life on earth several times over, or from blind and heedless experiments, both in the laboratory and in the battlefield, with biological and chemical weapons. Nor has it kept us from engaging in 'small' wars or aggressive actions that may lead to nuclear war. Even if a final, major war is avoided, preparation for it uses up physical and human resources that ought to be spent in an effort to find ways of feeding and housing the world's deprived people and of saving and improving the environment.

Science and technology have deeply aggravated the problems of life on our planet. Yet I cannot help but recognize that the solution of these problems will require more science and technology—not less. To me this suggests that new and improved ways of teaching and learning science must be devised and that science education must be closely linked with social responsibility. This raises the question of who bears the responsibility for future constructive uses of science and technology?

The social responsibility of scientists and the reciprocal responsibility of society

Having seen the havoc that has been wrought by the misuse of science and technology and the threat posed to mankind by it, some scientists have begun to ask themselves what they should do in order that mankind and our planet may survive. How can we, they ask, put science and technology to work for the benefit of mankind? Although it is proper for everyone, including scientists, to feel concerned and to seek modes of action to alleviate the situation, they alone will not be able to effect the necessary changes in society. The major decisions that will determine how science and technology are used in the future will probably not be made by scientists or engineers but, because of their knowledge, they have a particular responsibility to find means of influencing those decisions.

The events of the Second World War awakened many scientists to this responsibility and some of them joined existing organizations or formed new ones for the purpose of giving expression to this concern.

For obvious reasons the physicists who had worked on the bomb and other defence projects were among the most active. The *Bulletin of the Atomic Scientists,* edited by Eugene Rabinowitch until his recent death, is the prime example of a publication devoted vigorously to the cause of keeping scientists and laymen alike sensitive to their responsibilities in the precarious world that has emerged as a result of their work. For many years the cover of this magazine showed the hands of a clock approaching midnight—the symbolic hour of annihilation of the human race by nuclear weapons. In successive issues the minute hand approached twelve as the nuclear race marched on, apparently inexorably.

It took many years of effort, some of it by the readers of that journal, to push nuclear negotiations to the point where Rabinowitch decided that the hands of the clock had been temporarily stopped. The magazine continues as a journal devoted to the social consequences of science.

Space does not permit giving details, but I wish to recognize the existence of some of the other groups. The Society for Social Res-

ponsibility in Science (SSRS) had its origin in 1949 in the United States. Its membership now extends to twenty countries and includes many eminent scientists, among them Nobel Prize winners. Scientists and Engineers for Social and Political Action (SESPA) was formed in 1969 by a group of United States scientists and engineers who pledged not to participate in war research or weapons production, and to counsel their students and urge their colleagues to follow their example.

At about the same time a group of young British scientists were meeting regularly for discussions that eventually led to the formation of the British Society for Social Responsibility in Science (BSSRS). This organization is designed to make scientists aware of the social significance of science and of their social responsibility as individuals, and to assist scientists in creating an informed public that can exercise a choice in scientific matters.

Two other noteworthy activities differ in that they involved only small groups of the élite among scientists. They are the Pugwash Conferences started by Bertrand Russell with support from Cyrus Eaton, and the so-called Club of Rome.

Since the main task of the scientist is to do research for the purpose of understanding, whereas that of the engineer is to solve real problems and produce new materials, it is clear why Foecke [6] suggests that, of the two, it is the engineer who has it in his power to decline to produce things that may do damage to humanity and, more positively, to introduce into his proposals elements of creative design that will constitute real improvements.

It is perhaps understandably characteristic of some scientists, even among those who, like Nobel Prize winner Kastler, have expressed social concerns, to think that the pure scientist has as his main responsibility to remain in his ivory tower and to push back the frontiers of the unknown. They would argue, in other words, that without the knowledge and understanding that spring from pure research, eventually applied research and all mankind would be the losers.

But Rose [13] reminds us that even pure research costs money —'he who pays the piper calls the tune'—and that in fact the purest of research is to a great extent paid for by the richest of the clients of science, namely the war departments of the great powers.

In other words, the decision makers who wield the real power are either government agencies such as those of defence or (usually with less money at their disposal) departments devoted to health, education and social welfare but the great perversion of power has often occurred because of the partnership between big business and the defence departments—the so-called 'military-industrial complex'. This suggests that the scientist has the responsibility to do research and to learn but also to heed the admonition of Wald: 'Know all you can, but do only what you think is good.'

The scientist has a special responsibility in education not only

to assist in teaching graduate students but in helping choose the contents of university and pre-university curricula. He should devote some of his time to explaining, without using jargon, the significance of his own research so that laymen, including those in decision making positions, have the factual basis on which to make good judgements. Rose suggests that he 'can also affect the basic pattern of his own subject matter' by which I think he means that the direction of future research should not be left completely to the clients in government and industry but should be subject to the constraints of social responsibility as seen by the scientist himself.

As an example of how social responsibility can be shared by scientists, engineers, legislators and the general public in a democratic country where, in principle, they can influence the course of events consider recent actions to curb the increase of pollution in the air caused by the automobile exhaust.

It is the responsibility of the scientist to understand the laws of nature that relate to the production and propagation of noxious fumes and to inform legislators and the general public about them. It is the task of the engineer to make the necessary breakthroughs in creative design that produce the smog controlling device and it is his responsibility to propose its use to management. It is the responsibility of management to make the decision to incorporate the anti-pollution device in the production plans for the well-being of society as a whole, and it is the duty of the legislature to pass laws requiring the introduction of anti-smog devices. Finally, it is the responsibility of a concerned and well-informed public to exert pressure on their legislators demanding the passage of anti-pollution laws.

The science educators of the future must take into account the social responsibility of all groups mentioned above.

The changing concepts of social and economic development

The characteristics of developing countries

The great difference between developing and industrialized countries is not immediately apparent to the casual visitor to a developing country. On arrival, he sees the same jumbo jets, long runways and glass and concrete airport buildings. He shops for elegant articles of

clothing typical of the region and comes on the same displays of transistor radios, portable cassette television sets, cameras and play-back units.

If he goes to a hotel belonging to an international chain, he will find practically all the comforts found in hotels in advanced countries.

In the smaller and more modest local hotels, the signs of under-development are more visible: the pressure in the shower is usually lower, it takes longer to reach a telephone number, the temperature of the water that comes out of the hot water tap is usually lower, but the temperature of the water that comes out of the cold water tap is usually higher than in the advanced countries (most of the developing countries are in a belt between 30° north and 30° south of the equator). The interval between the actual starting time and the announced time for a public event is usually longer and can be as high as several hours. The efficiency of postal systems is low although the postage stamps are often more aesthetically attractive. The variety of foodstuffs available to a working family is low except for fruit and vegetables in season. The number of street lights is smaller and the total illumination is less.

Most of these indicators are linked with the fact that industrially and technologically the developing countries are lagging, but artistically and philosophically the people may be more advanced than their counterparts in the industrialized countries. They may already be in a state of closer ecological harmony with their environment, a state which the industrialized countries are now only beginning to strive for. Courtesy and politeness which, at their best, are indicators of warmth and human concern are probably in greater abundance in the developing countries than in the industrialized sectors of all countries.

All countries are, of course, developing, but the term developing countries has been adopted—somewhat euphemistically, it seems to me—for what have also been called the underdeveloped countries or the less developed countries. I shall adhere to the term developing countries in deference to its adoption by international organizations such as the United Nations and the World Bank.

In contrast, I will often use the term industrialized countries for what are also called the developed or the advanced countries. It would have been more straighforward, perhaps, to speak simply of the rich and the poor nations, the haves and the have-nots because the one characteristic common to all the developing countries is poverty and that which characterizes the developed world is wealth which springs in great measure from industrialization.

We described earlier what it means in human terms to be poor. Hunger, disease and illiteracy are, therefore, high on the list of characteristics of developing countries. We did not stress an important economic factor, namely, that a great many people in developing countries work in agriculture. They do so often in the back-breaking

labour-intensive way characteristic of pre-mechanized agriculture. This is borne out by the following data concerning some of the countries in the four lowest levels of economic development [14].

Table 2. Indicators of human resource and economic development

Indicator	Level I (17 countries)	Level II (21 countries)	Level III (21 countries)	Level IV (16 countries)
Mean GNP *per capita* per year in U.S.$	84	182	380	1,100
Percentage of active population in agriculture	83	65	52	23
Teachers (1st and 2nd levels) per 10,000 population	17	38	53	80
Scientists and engineers per 10,000 population	0.6	3	25	42
Physicians and dentists per 10,000 population	0.5	3	8	15

Even these few indicators from a small sample of countries give us a feeling for the state of agriculture, education, medicine and science in the developing world. They are quantitative measures and tell us nothing of the services in these sectors, but the low figures for scientists, engineers, physicians and dentists suggest strongly that the quality in these sectors cannot be high.

Another characteristic of people in the developing countries which still exists but which tends to diminish as the gap between the haves and the have-nots increases is the hope for the future. Perhaps a science education relevant to real needs could generate the basis for increased hope.

Aspirations toward social and economic improvement in developing countries

The aspirations of the developing world have been stated in moving terms by K. B. Asante of Ghana [15]:

Our world is polarized into haves and have-nots. It would be wonderful if Neil Armstrong spoke for all mankind when he said on landing on the

moon: 'One small step for man; one giant step for mankind.' Though I was excited and sat with my eyes glued to television until the early hours of the morning, I did not feel he spoke for me. I do not belong to that part of mankind. But I and countless others want to belong to one mankind.

People in developing countries want to belong to the part of mankind that has the capability for doing something as grandiose, exciting and possibly historically meaningful as sending a man to the moon. But they know that they are so mired in poverty and its attendant miseries —hunger, disease and deprivation—that it seems a dream impossible of attainment. Some of them have seen on television how people in the industrialized countries live and they aspire to the comforts and conveniences which higher productivity and higher income have brought to them. They are caught up in what has been termed 'a revolution of rising expectations' but they are feeling the psychological stresses produced when people see and hear of better forms of life but are deprived of the means of attaining them.

People everywhere have the same longings for peace, health and prosperity—some of the basic ingredients of happiness—but only in the industrialized countries, it seems, do the majority of people have meaningful work to do and the level of economic well-being to fulfil these desires.

Before any of the higher dreams of well-being can be fulfilled, therefore, it seems clear to all that the basic needs of jobs and food must be satisfied. In other words, the first requirement is a minimum level of material well-being. For this, science and technology must be tied to economic growth in a way that is suited to the needs of the developing countries. Their leaders know this but often do not know how to get started. It seems only natural for them to consider industrialization as the solution, since it worked in the advanced countries, but the task of building the infrastructure for the kind of industrialization that is best suited to their needs is a difficult problem in long-range planning, involving a policy for science, technology and educational development.

The developing countries have, of course, a right to aspire to a better way of life but the implications of their achieving a level of prosperity anywhere near that which at present prevails in the advanced countries has created a serious predicament. The rather recent energy shortages in the advanced world have caused everyone to be suddenly aware of the global limitations on natural resources on which mankind depends for energy, food and other basic needs. The realization that the earth is like a huge space ship whose resources must be conserved and recycled has suddenly hit the advanced countries. Not only will they not be able to meet their own rather exorbitant projections for energy needs, but the energy needs of the developing countries, even calculated on their present very modest consumption rates, would be difficult to meet thirty-five years from

now when their total population will be doubled, let alone their energy needs should they be even half way up the industrialization ladder at that time.

In other words, the energy and resource needs of the developing countries, should they become industrialized, would present demands on the sources of energy, natural resources and food supplies which would be impossible to satisfy.

Such, then, is the predicament. Both the developing and the industrialized countries foresee the need for greatly expanded resource and energy utilization but even now the industrialized countries take the lion's share. They will have to learn to live on a more modest scale. No one would deny the rights of people in the developing countries to a greater share than they have at present, but since the bulk of the population increment will be theirs, they will have to distribute their hard-earned and newly acquired wealth among more people. Hence they will not be able to enjoy the increment *per capita* that they would have if their population had not grown so rapidly.

It seems to boil down to this. People everywhere must learn to live with the concept of a world whose resources are finite. The present advanced countries will have to learn to live more modestly and the developing countries can expect an improvement in their economic well-being only if it is in return for hard work and imaginative thinking applied to the creation of suitable technologies and a pragmatic approach to the limitation of population. Both the newly independent countries and the affluent ones must come to the realization that all of us may soon have to draw up a charter of interdependence. Taking this into account, we have to rethink the present concepts of development.

The concepts and mechanisms of development—old and new

We are well into the Second United Nations Development Decade (1970–80) during which a concerted international effort is being made to improve the social and economic conditions of the developing world.

An important idea that grew out of the hard work of running the development programmes of the 1960s was the realization that international collaboration was necessary and that all countries, rich and poor, stand to gain from the improvement in the lot of the developing countries. Lester Pearson in his book *Partners in Development* [7] says:

> Who can now ask where this country will be in a few decades without asking where the world will be? If we wish that world to be secure and prosperous, we must show a common concern for the common problems of all peoples.

During the first decade it was recognized by the leaders of the developing countries that sciences and technology could play an important role in development. H. J. Bhaba of India put it bluntly when he argued that what the developed countries have and the developing countries lack is modern science and an economy based on modern technology.

How complex this problem really is began to appear when the Economic and Social Council of the United Nations decided to explore ways of harnessing recent advances in science and technology to development. At the United Nations Conference on the Applications of Science and Technology for the Benefit of the Less Developed Areas, in Geneva in 1963, more than anywhere else was it first realized how complex the over-all problem was. As a result, the United Nations Advisory Committee on the Applications of Science and Technology to Development (ACAST) was created the next year. During its meetings, held in the 1960s, this committee was to define and refine the whole notion of scientific development. A concise summary of its activities and plans for a second United Nations Development Decade are given in Robin Clarke's booklet *The Great Experiment* [16]. He writes:

> ... [We] know that science and technology are no magic panacea—that the pouring of even greater funds into ... bottomless coffers will not necessarily lead us to that Golden Age where man can live in dignity and peace and with a full stomach. This new knowledge—scarcely older than a decade or so—is supremely important, as important perhaps as the promise of science itself.

The optimism of the early 1960s gave way to the disillusionment of the 1970s when the old concept of development based primarily on economic growth began to be seriously questioned.

Jackson wrote in 1969 [15]:

> Development assistance has evolved from a marginal activity to a central concern for both developed and developing countries. But this growth has been accompanied by an increasing feeling of disconcertment about the role of outside aid and its effectiveness. . . . There can be no instant development, no blueprint for success, and no single development approach.

After expressing admiration and sympathy for the administrators of the United Nations programmes, he concludes:

> But none of this should mask the basic, sobering truth: that, in the final analysis, the principal losers were the developing countries, because the cumbersome machinery devised over the years could only be maintained at the expense of the operational efficiency of the programmes of co-operation carried out on their behalf.

Another source of disillusionment has been the fact that the industrialized countries have been less than generous in supporting international assistance programmes. The United Nations programmes in the early 1970s asked donor countries to provide $300 million a year and they gave only $240 million. This is discouraging at a time in history when it is clear that they should be giving more—not less.

At this moment, the industrialized countries have suddenly felt the energy pinch that threatens to change their affluent way of life, and in some of them there is talk of girding themselves for hard times ahead when economic survival rather than affluence will be the target. In the light of this, we must try to imagine how hopeless the situation must seem to a country like India when it realizes that the increase in *per capita* GNP of the United States in one year equals the increase that India may be able to manage in about 100 years!

So far I have expressed the point of view of those in charge of aid programmes. How about the point of view of people in the developing countries? Dr Mahbuh Ul Haq, a senior economic adviser at the World Bank, says:

> The developing countries are passing through a very dark and ugly mood . . . for about two-thirds of humanity the increase in *per capita* income has been less than one dollar a year for the past twenty years.

Dr Ul Haq considers that the developing countries are themselves partly to blame in that they sought high growth rates in the Gross National Product regardless of how that growth was distributed. He has said that Pakistan and Nigeria have turned into 'development disasters'. He apparently now advocates a new strategy embodying a direct attack on mass poverty, a genuine turn toward socialism and a far greater degree of self-reliance.

He also advocates a redefinition of social objectives of truly staggering proportions, a liquidation of privileged groups and vested interests and a redistribution of political and economic power through revolutions rather than through evolutionary change.

Ul Haq rejects the theory that the stimulation of high growth rates results in the trickling down of wealth to the masses. He advocates, instead, a direct attack on mass poverty, claiming that the focus of development efforts should shift to the poorest 40 or 50 per cent in society. National production targets should be aimed at the basic needs of these poor and not be governed so largely by market demand. Otherwise, production will go to the well-to-do and not the poor. Development should be aimed at the progressive reduction and eventual elimination of malnutrition, disease, illiteracy, squalor, unemployment and inequalities.

Speaking of the record of foreign assistance he says:

> It is beginning to convince me, as it has convinced many of my liberal colleagues, that the developing world would have been better off without such assistance.

S. Husain Zaheer of India differs from some of the opinions of Ul Haq. He suggests that prosperity might be attained in developing countries through an effort to bring about a growth of science and technology in the developing countries, on the one hand, and, on the other, massive international co-operation and assistance by the rich nations.

Although their proposed solutions differ, it is clear that they and other critics believe that development efforts to date actually went off on the wrong track and that a drastically new direction is needed.

A recent issue of the magazine *Science for the People,* for example, states that

> the consequences of 'development' depend on who the developers are, that technology and class ideology are considerably interwoven, and that development under global capitalism is really *mis*development. Our view is that we must change the social structure to create a new role for science and technology that serves all the people without exploitation.

These critical opinions are succinctly summarized by the words: economic growth is not necessarily development. The new approaches to education in science and technology must take these criticisms into account.

Guidelines for future development schemes

In summary, if we are to profit from the mistakes of the past, alternative development schemes of the future will have to take the following factors into consideration:

There is a universal longing for human happiness and a corresponding search for a higher quality of life. Development schemes to date have concentrated on economic growth as a means of achieving these human goals but there is a growing recognition that wealth and possessions are not enough. Other factors—psychological, social and political—must be taken into account.

For the poorest countries, however, a better way of life demands that highest priority be given to economic improvement, provided means can be devised to see that it is used at once to deal with the basic problems of hunger, disease, malnutrition and illiteracy.

The benefits of economic growth must reach the poorer sectors of societies much faster than they do at present. This may require drastic political reorganization within some countries in order to prevent the increased wealth from being concentrated in the hands of a powerful minority.

For the benefits of economic growth to reach poor people faster, technologies which are appropriate to the special needs of the

developing countries must be fostered. Some research on these problems can be done in the donor countries, but the more that is done within the developing country itself and by its own people, the greater the chance that the solution will be realistic, viable and highly motivated for implementation. Implementation may require stepping up labour-intensive technologies to distribute the work load and hence the economic benefits over a larger sector of the population.

In order to remove the gross inequities which exist between the poorest developing countries and the richest industrialized ones there has to be a massive step-up of aid from the industrialized countries. This must be free of political and other strings.

This aid had better be administered by way of multilateral agencies such as those of an improved United Nations Development Programme in order to avoid the temptation to use it for political ends as has happened in some bilateral aid programmes.

People everywhere will have to recognize the ultimate interdependence that is forced upon us by economic, environmental and ecological factors. Recognition that we live on a finite globe with finite resources may force us to move toward patterns of behaviour associated with the concept of world brotherhood. Perhaps in this way the dreams of philosophers, religious leaders and mystics of the past may one day come true.

The development of human resources is probably at least as important as the development of natural resources. This will require the proper and realistic education not only of scientists and engineers but of people specialized in other fields such as agriculture, economics and the social sciences. The development of natural resources in a developing country exclusively by experts from abroad will not produce the educated manpower needed for eventual self-sufficiency.

This leads logically to a consideration of the role of science and technology education.

Implications for science and technology education

Why are science and technology education needed for economic and social development? The first reason is that scientists and technologists are required in the economic infrastructure of an industrial society no matter how unsophisticated it may be. Agriculture, food, shelter, medicine and the industries associated with them, on which material well-being rests so heavily, require personnel with scientific and technical training. The second and possibly the more important reason is that, properly integrated into the educational programme, they can infuse the whole educational process with a confident and competent

approach to problem solving which has met with extraordinary success in the industrialized countries. If all students in the developing countries, including those in the arts and the humanities as well as those in science, were imbued with the curiosity that characterizes scientists and the competence that characterizes engineers and technologists, all would be in a better position to participate in the solution of the indigenous problems of social and economic development.

The role of decision making deserves special attention. The making of choices and decisions between different alternative solutions to a practical problem is a process in which the engineer is more deeply involved than the pure scientist. As I said earlier, the scientist is concerned with 'what is' rather than with questions of 'what can be' and 'what should be' which confront the technologist and engineer. We must not forget, however, that the ultimate decision of 'what shall be' is made by the people with power. Heads of State, ministers, politicians and leaders of industry are examples of such people. I believe we would all be better off if they too were imbued with curiosity, creativity and competence. To me it seems clear that what they need most is intelligence, knowledge and good will because, with these, they could surround themselves with people of ability to draw up and execute a sensible science and technology policy for their country. Perhaps they need even more the attribute of compassion, by which I mean a feeling of concern and social responsibility. It is hoped that the general as well as the science and technology education of the future will generate this very urgently needed ingredient in the decision makers.

In the light of all this, what should be the broad characteristics of science and technology education if it is to respond to the real needs of developing countries? I suggest the following as guidelines.

It should be practical, relevant and appropriate. It is easier to write down these words than it is to spell out operationally what they imply in the development of educational programmes. They imply, among other things, that the decision makers have stated their national priorities clearly and that they recognize to what extent it is better for them to utilize existing technologies and patterns of industrialization from advanced societies than to generate their own. Much of what passes for science education in developing countries is far from being practical, relevant and appropriate if the goal is to generate the future manpower that can solve internal problems without outside assistance. Particular attention should be given to the activities associated with problem solving, decision making and design which are more closely related to those of engineering and technology than they are to those of pure science. Hence technology should probably be integrated into the teaching of science in the early years considering the fact that in two-thirds of the world most children will not go beyond a few years in the elementary school. The development of intermediate and appropriate technologies requires people with a

degree of imagination and courage that is often not produced by the classical and authoritarian methods of teaching science used in the past when different scientific disciplines were taught in separate, airtight compartments. Hence the advantages of teaching the sciences along with technology in co-ordinated and integrated ways should be given serious consideration.

It should promote adaptability to change. Accelerated change is one of the important characteristics of a developing country embarked on a dynamic programme of social and economic development. Once again, it is more important that students acquire the frame of mind associated with discovery and inquiry than it is for them to memorize facts whose value may be transitory. There are some broadly important principles with a longer half-life than others. The concepts of conservation of energy and momentum in physics, for example, will probably still need to be taught and understood fifty years from now regardless of the course of modern research. It would be good to stress such basic and unifying concepts while also emphasizing activities of the problem solving type, preferably dealing with problems that are real in the local economy.

It should be useful in improving the lot of the poor in as short a time as possible. This is a criterion that has not been considered seriously in the past. The feeling of desperation that grips those of the poor who have an opportunity to be educated is that so much of what they have to learn seems of no use in the solution of their immediate problems. As I said earlier, this is the great concern of economic thinkers like Ul Haq who feel that drastic changes are needed in the political systems of the developing countries if they are to make a noticable improvement in the economic and social status of those in the least privileged categories.

It should recognize the eventual global interdependence into which the energy and environment crises are driving us. I recognize that it is very difficult for people in the poorest countries to think about global problems of society when the immediate problems of hunger and malnutrition, in their local communities, cry out for immediate action so loudly that they are prone to set aside such problems as family size limitation and pollution. But the leaders in the developing countries must become aware of the extent to which all of our fates are intertwined. As soon as we are gripped with the notion of a planet of limited resources we recognize that in the future there will certainly not be enough energy and resources to go round if all of us insist on living at the wasteful standard presently set by the advanced countries. Naturally, great efforts must be made to improve the material lot of the people in the poorest countries, and the advanced countries will have to make sacrifices in order to help, but the realization of the stark fact that we live on a finite planet faces all of us, rich and poor alike.

It should avoid freezing itself into an immutable system. The

system of science and technology education must learn from its mistakes how to improve itself. This pliability is hard to establish and preserve in any bureaucratic system because personal and clan interests tend to take control.

2

The goals of innovative activities in science education

What do we want to see in the science education systems of the future? Long-range goals

If we think of this book in terms of a journey we should now be asking ourselves 'Where do we want to go?' A scientist from a developing country once asked me, 'Whom do you mean by we?' He complained that he had attended many conferences on science education improvement where the experts from advanced countries seemed to be intent on pushing their own goals and solutions on to the developing countries without having considered their real needs. I shall try to avoid that error. I believe firmly that the ultimate decision on what a given country needs rests squarely on the shoulders of its own decision makers and that if there is to be assistance from the outside it should fit in with the national plans.

In this chapter I plan to deal with long-range goals in a very general way. As I observed earlier, when I say 'science education' I have mathematics in mind as well. I also envision that some aspects of technology education will be absorbed into science education or at least planned for simultaneously. To further clarify the sense in which I am using certain words, in this chapter, the word 'system' will be used in its ordinary sense and not in the sense of 'systems analysis' which will be discussed in Chapter 5. I have also chosen the word 'goals' rather than 'objectives' because the latter is a term now often used in the context of 'behavioural objectives', also to be treated later on.

I will be speaking, therefore, of very general long-range aims and I will not spell out at this time the details of what I mean by innovative activities. Here, then, is a list of general goals for science

education evolved by a group of thirty scientists and educators from both the advanced and developing countries, more or less evenly divided, at a meeting convened by Unesco in 1971. Confronted with the basic question: 'Why teach science?' the members of this group responded, after collective thought and deliberation, essentially as follows:

Science teaching should be carried out in such a manner as to encourage each pupil ('student' would have been a better word since everything that follows applies to university students as well) to:

Understand man's environment and apply accumulated knowledge and experience to deal with the problems posed by it; heighten his curiosity of scientific inquiry as well as his imagination, initiative and involvement; appreciate the place of science in the world at large and form and develop a scientific view of it.

Understand the methods of science such as the use of data and the pratice of logical, objective, analytical and critical thinking.

Utilize experimental approaches and acquire the ability to devise and carry out experiments, observe and record data, reach conclusions, draw generalizations and learn to test them.

Use plain and concise language to clarify and evaluate information, employing mathematics when necessary.

Improve his capacity to learn from experience, criticize his own work, admit error and respect the point of view of others.

Learn the system of concepts, skills and applications of the various scientific disciplines and the interrelationships between them.

Understand rather than memorize by rote.

Utilize scientific models and appreciate their powers and limitations.

Enlarge his interest in science in order to choose a useful and meaningful career in science, technology or a related field.

Comprehend the philosophy and the history of science and its contribution to the development of the modern world.

Apply scientific knowledge and methods in daily life and tackle practical problems at individual, local and national levels.

Develop a sense of social responsibility.

Because social responsibility was put last and seems to be an afterthought I should like to express my own opinion in which the human aspects of education are given more weight. I believe that the ultimate aim of science education, over and above that of training scientific and technological manpower, should be the development of sensitive human beings, informed and competent in the subject-matter and methods of science, and possessing a sense of social responsibility.

Who is responsible for choosing and implementing the long-range goals?

The list of goals given above was drawn up by scientists and educators. From their own knowledge of science they were able to state what they considered to be desirable goals for science education but they are not the ones who have the power to put into effect a programme based upon these goals.

The decision makers, especially in the ministries and in industry in the developing countries, are the people with political power and they very seldom have a scientific background. It is true that they often have a broad and general grasp of the economic benefits which accrue to countries with technological know-how and they see the advantages which modern technology can bring to a country. Naturally they would like their country to have them, but they may not be fully aware of the growing need for all citizens to have a general education which is imbued with both the spirit of inquiry and the approach to problem solving characteristic of technology.

The decision makers, often at the level of ministers, have seen that science and technology have brought to the industrialized countries power over nature, life, death, sickness and people and they aspire to the same. They see that only religion, perhaps, has affected the lives of human beings as profoundly as technology. Only some of them realize that although they can buy the fruits of technology if they have the money (and most of them do not have enough) they cannot have the long-range benefits of science unless they educate a new indigenous generation to cope with accelerated change—the most characteristic feature of a technological society.

One thing is certain, regardless of what they do or do not understand about science, they have the power to make decisions on the implementation of science education programmes and it behoves the scientists, technologists and educators to communicate with them at a level and in a jargon-free language which they can understand. Otherwise none of the noble dreams symbolized by the list of long-range goals given above will ever materialize.

Let us, however, face the reality that science and technology have been a mixed blessing in the advanced countries. Along with a wealth and material comforts that come with industrialization, they have also brought with them the perils mentioned earlier, including noise, pollution of air and water, depletion of natural energy and other resources, disturbance of the ecological balance and even weapons of mass destruction. Are the developing countries headed down the same

path? Some of them are, unfortunately, and these include the countries most eager to advance their systems of science education.

One of the most important questions for the decision makers, it seems to me, is to find out whether the introduction of new goals for science education can help them redirect their efforts to avoid what seems like unavoidable disaster. Can the developing countries learn their science and technology in ways that will enable them to acquire more of the benefits and fewer of the evils? My feeling is that it is possible provided we stress the kinds of goals that imply learning behaviour patterns which go far beyond those that have in the past been normally taught in the science classroom and laboratory. The goals cited above can serve as guidelines for decision makers if they understand their full meaning and importance. It is the duty of scientists and educators to see that they do.

In all countries, the decision to strengthen science education is, at least in part, a political decision. It involves allocation of huge sums of public money. Educational aims are often chosen by law-makers and politicians who have only a vague idea of what is involved. Since they are seldom scientists themselves, when they get advice from scientists they naturally weigh it against opinions from other sources or rely heavily on their intuitions, basing their decisions on what is politically expedient.

Here are three of the many opinions about science and technology which decision makers have probably heard:

Without indigenous science and technology the natural and human resources of the nation cannot be organized for industrial expansion or national defence.

Economic and social development require a climate of popular understanding and acceptance of science.

Science can help overcome ignorance, superstition, fear and poverty.

Of these three opinions, the first is the one that they are most likely to accept although I imagine many of them have not thought through the implications of the word 'indigenous' since it must be obvious to them that it is possible to purchase some of the fruits of foreign technologies without any apparent need for indigenous scientific manpower.

The decisions they ultimately make about science and technology education depend, of course, on their own personal motives as well as on those of the nation-State which they serve. Some leaders may actually thrive personally if ignorance, superstition and fear persist among the masses! The motivation for science teaching reform has even been the fear, based on military and political considerations, that another nation may get ahead in the technological armaments race.

The explicit objectives of science teaching reform that will emerge as national policy are, in other words, based fundamentally on the aims and motives of people, the people in power. These people

bear responsibility for answering such philosophical questions as: 'What are the real needs of society?' or 'What do we want the young people of tomorrow–the products of our schools—to be able to do as a result of science education that their present counterparts cannot do?' It is at this point that decision makers need assistance. They ought to have a clear understanding of what science and technology are all about. Where should they turn for help?

If all that were needed was to choose the relevant content for the new curricula, they could turn to research scientists for help since they know what is at the cutting edge of research and hence what will probably be important in the near future. They can suggest what to delete from old curricula and what to add to the new. In the realm of methodology a band of experts has evolved within the last fifteen years, including educational technologists to whom they can go for advice on how pupils learn and how they should be taught. But where should they turn for expert advice in the realm of aims and objectives? There are no 'experts' in this area. Yet those who make decisions in this realm can influence the course of science and technology education negatively through error or positively through understanding. The guidance politicians need from experts in the realm of science education is comparable in importance to that which they need from scientists concerning nuclear energy, natural resources and science policy. Let us hope that the advice they get is better than that which some of them received concerning the construction and use of weapons of mass destruction.

There was a time when scientists and educators were willing to accept educational guidelines from the decision makers and follow them blindly as if they were physical boundary conditions like those imposed by nature and over which man has no control—there is not much point, for example, in planning physics experiments as if the force of gravity did not exist. I think, however, that we are entering a new era in which it is part of the social responsibility of scientists and educators to assist and even advise politicians on the scope, the power and the limitations of science so that they, in turn, can make realistic decisions towards a national science policy which reflects worthy and achievable goals in the realm of science and technology education.

Is there an ideal system of science and technology education that applies to all countries?

The answer to this question is clearly 'No' There is simply too much variety in the countries round the world. Some are densely populated, like Monaco (16,000 persons per square kilometre) and some are sparsely populated, like Greenland (0.02 person per square kilometre). Some have a high life expectancy, like Sweden (74.2 years) and some have a low life expectancy, like Guinea (27 years). Some have a large population, like India and China (542 and 759 million, respectively) and some have a small population, like Pitcairn Island (approximately one hundred people) and, of course, as was pointed out earlier, some are rich, like the United States (GNP per person over $4,000) and some are poor, like Burundi (*per capita* annual income approximately $40). These differences indicate vastly different levels of social and economic development and corresponding differences in the kinds of science and technology education needed.

Their educational systems have also developed along different lines. In many of the European countries, for example, and in other places as well, the national educational system is highly centralized. Authority for the implementation of science education is the responsibility of a ministry of education. In some countries, especially in Eastern Europe, innovation and reform in science education are in the hands of pedagogical institutes responsible for research, leading to choice of curricula and the development of textbooks and other learning materials which are mass produced, effecting great savings, and used in every school in the land. A country like the United States, on the other hand, has fifty separate states bound together by a federal government, each autonomous and independently responsible for the development of its educational system. There is a National Science Foundation which has sponsored research and innovation in science education but its materials have been adopted or adapted by the states or by individual schools by choice and not by necessity. The production of textbooks and other learning aids is in the hands of private entrepreneurs, writers and business firms competing in the open market. This results in a tremendous variety of textbooks in science which are then chosen on a competitive basis by the public and private schools throughout the land. This kind of autonomy and independence exists also in other large countries at different stages of development like Brazil which has several independent states and India which also has independent states. This is not the place to discuss the relative merits of systems with centralized authority over those in which the

authority is decentralized. There are obviously fewer decision makers in those of the first category but the over-all quality of the systems would have to be judged on other factors as well. I simply wanted to point out that because of these and other differences no single system of science and technology education exists which is applicable to all countries.

A check list of future needs in science education in developing countries

We started out by asking: What do we want to see in the science education systems of the future?' We have reached the tentative conclusion that no single system would serve all countries. Can we, nevertheless, produce a check list that gives some idea of what we mean, operationally, by a system that might serve as a practical ideal? I think it is possible to do so if we limit our consideration to the needs of developing countries and to schools at the pre-university level. In spite of these limitations, readers who are interested in the problems of the industrialized countries and/or the problems of university science can probably extrapolate or modify the check list to make it applicable to their needs.

The list represents a personal point of view but it is one which integrates thoughts collected over more than fifteen years of involvement in the science education improvement movement in both developing and industrialized countries.

I tried to imagine what a classroom of the future in a developing country might look like several years after a successful, concerted, world-wide attack on the problems of science education has been launched. I cannot imagine any science educator from the developing countries I have visited or worked in who would not agree that the following represent worthy and in many cases achievable goals. Here is what we should see as we enter this hypothetical classroom of the future:

A well-trained teacher, in good health, not too overloaded with work, alert to the individual needs of students, not authoritarian, permitting class discussion, sensitive, and proud of his or her task which is not simply to dispense the facts of science but to create an environment in which learning can take place.

A large classroom with plenty of air and light and adequate control over temperature, humidity and noise level.

Students in good health, alert, interested and adequately dressed for local weather conditions.

A room in which there is mobility and flexibility of desks, chairs, walls, carrels and utilities, with plenty of space for sitting, walking and working.

Not too many students per teacher.

A good chalkboard with chalk and erasers that really work well or their modern optical or electro-optical counterparts such as projectors for overhead transparencies or closed-circuit television.

Each student with his own copy of a good textbook or its self-instructional and self-testing counterpart, modern in content and illustrated to take into account special cultural and regional needs.

Laboratory equipment in sufficient quantity and some of it inexpensive enough so that breakages can be overlooked and so that each student may handle it himself. Laboratory and field procedures in which students are encouraged to learn not only through their eyes and ears but also through the use of their hands.

Enough pieces of the more expensive types of equipment necessary for instruction, such as barometers, electric meters, microscopes, oscilloscopes, etc.

A teacher who makes use of a good teacher's manual, written with the help of a team of specialists including scientists, educators, educational technologists and graphic artists with lots of illustrations and suggested tests and demonstrations to guide him.

Associated with the classroom, a library with a variety of supplementary reading, audio and visual materials for both teachers and students.

A teacher who has a reasonable teaching load and a salary attractive enough to make it unnecessary for him or her to take a second job in order to make a living; with the opportunity for continued self-improvement through in-service training which consists, at least in part, of participating in the development of new teaching aids and materials at a well-equipped science teaching centre.

Some of the newer materials for learning, such as films, filmloops, filmstrips, sound-tape, video-tape, cassette television, audio-amplifying equipment and computers for the use of students and teachers including computer-assisted instruction.

A teacher following a programme not too slavishly tied to a uniform curriculum or syllabus, taking into account individual differences among students and flexible enough to provide work that challenges but does not overwhelm students of different levels of ability.

Tests and examinations developed with the help of educational technologists to provide continual assessment of the students' progress and thus avoid the trauma that sometimes results from inaccuracies in the assessment of the single final examination. Assessment is primarily used as a means of facilitating learning and not as an arbitrary barrier or simply as a means of classifying students.

A modest workshop where simple pieces of experimental equipment can be built and repaired by the teachers and/or students.

A situation where an attitude of inquiry and openness towards questioning on the part of students is encouraged; where 'learning begins in wonder and ends in delight'. Other situations where the students participate in the solution of simple but real problems, relevant to the improvement of local conditions, using the procedures of design and decision making associated with engineering and technology.

A teacher with sufficient confidence, based upon adequate mastery of content and methodology, to say about certain questions posed by the students, 'I don't know' followed by suggestions on how both teacher and pupil may proceed to find the answer.

I think if the reader pauses after each of these points to consider the present situation in the science education systems of his country, whether it be developing or industrialized, he will discover that there is still plenty of room for innovation that may lead to improvement.

3

Present status and improvements needed in science education

A broad comparison of present systems and projected goals

For the reasons given earlier I will focus strongly on the needs of developing countries in this chapter. I believe my comments will be relevant in other countries as well.

One approach would be to give comparative statistics that describe the general characteristics of educational systems round the world. Another would be to compare the details of current practices in science teaching with the ideals set forth in our check list of Chapter 2. I shall do it both ways, in that order.

Expenditure on education in the developing countries is much less than in the industrialized world. This is brought out clearly in the statistics of Table 3.

Table 3. Education in the developing and developed countries (1967/68)

Parameter	Developing countries	Developed countries
Percentage of total world population (all ages)	73	27
Percentage of total world population in the 0–15 age group	78	22
Public expenditures on education (in million dollars)	10,420	108,670
Gross National Product (1967) (in million dollars)	292,500	2,102,800
Public expenditure on education as percentage of the GNP	3.6	5.2

Source: S. Ramakrishna and R. Seshamani, *Science Education in Developing Countries*, p. 5, Bangalore Indian Institute of Science, December 1973.

For every \$37 spent on a pupil in the industrialized countries on the average, only \$1 is spent per pupil in the developing world. The public expenditure on education in the developing countries expressed as a percentage of the GNP is a surprisingly high 3.6 per cent, indicative of a heroic effort on their part. It compares favourably with the 5.2 per cent of the industrialized countries but the financial resources of the latter are relatively so great that the imbalance is alarming.

Table 4 contains much information which is indicative of the precarious state of education in the developing countries. They are burdened with growth rates much higher than the world average and large increases in absolute numbers because of the size of the base population. Asia has the largest increase (318 million) because it had the largest base of population (1,645 million) in 1960 coupled with an above-average growth rate—2.23 per cent in the period 1960–68. Other features are the high concentration of students at the primary level and few opportunities for access to higher education. In terms of teacher-pupil ratios the developing countries are again handicapped. Adult illiteracy is also very high in the developing countries.

A problem which is particularly acute in the developing countries is that of wastage—high dropout rates—in the early grades. In virtually all of the developing countries the number of dropouts at the primary level is enormous (see Table 5). Usually, for every two children who enter the first grade of the primary level only one child remains at the fourth grade. Under these circumstances educational planners are forced to consider seriously what should be taught in science in these early years and how it should be taught if it is to have a lifelong impact. We shall return to this question when we discuss integrated science.

I have not been able to find interesting statistics to summarize the state of world-wide science education but there does seem to be a pattern of science education in schools which is more or less the same in the different regions of the world. Science is usually introduced, for example, as a general science subject in the lower classes up to the junior secondary stage (Grades I-VI, corresponding to the average age group of 5–13 years). The general science course incorporates simple illustrations from nature, related to all aspects of life in the world, and presents progressively more difficult concepts as the pupil enters the higher classes.

Usually from Grade VII onward, up to the final year of the secondary level, specific science subjects like mathematics, physics, biology, chemistry and earth-science are introduced into the curriculum. These are normally taught by a separate teacher of science for each discipline. Credits per hours per week allocated to science are approximately 30 per cent of the total number of credits, with minor variations from region to region.

Table 4. Education in the developing and developed regions

Parameter	World total	North America	Europe and U.S.S.R.	Oceania	Africa	Latin America	Asia
Population							
Total (millions) 1960	2,982	198	639	16	269	214	1,645
1968	3,492	222	693	19	327	268	1,963
Annual rate of increase 1960–68 (percentage)	1.99	1.40	1.01	2.10	2.45	2.87	2.23
Actual increase 1960–68 (millions)	510	24	54	3	58	54	318
Public expenditure on education as a percentage of GNP	5.0	5.9	4.7	4.5	4.2	3.6	3.8
Pupil distribution by educational level (percent) 1969/70							
Primary	71	53	67	65	85	79	77
Secondary	23	34	27	30	14	19	20
Higher	6	13	6	5	1	2	3
Teacher/pupil ratios (1969/70)							
Primary	1 : 30	1 : 25	1 : 24[1]	1 : 28	1 : 40	1 : 32	1 : 35
Secondary	1 : 18	1 : 19	1 : 15[1]	1 : 18	1 : 22	1 : 13	1 : 21
Higher	1 : 13	1 : 13	1 : 12[1]	1 : 13	1 : 13	1 : 9	1 : 14
Illiteracy rate[2] (percentage)	34.2	1.5	3.6	10.3	73.7	23.6	46.8

1. Ratios for Europe only.
2. Ratio of illiterates/total population in the age group 15 years and over.
Source: Unesco Office of Statistics.

Table 5. Estimated percentage primary school dropouts in some developing countries

Countries	Grade I	Grade II	Grade III	Grade IV	Grade I-IV
Africa					
Central African Republic	21.8	11.7	9.6	7.1	42.0
Dahomey	24.5	12.8	10.7	11.0	47.7
Madagascar	18.1	10.6	13.6	23.4	51.5
Niger	12.6	4.8	12.0	5.0	30.4
Togo	3.1	1.9	1.0	2.0	7.8
Upper Volta	19.2	17.3	7.3	16.7	48.4
Asia					
Afghanistan	4.0	1.5	2.0	7.0	13.8
Ceylon (Urban)	15.6	7.5	9.7	10.6	37.0
(Rural)	17.4	11.4	11.7	12.8	43.7
Philippines	9.2	6.8	7.6	10.0	29.6
Thailand	12.0	5.0	6.0	—	21.4
Latin America					
Argentina	13.4	5.6	7.6	10.0	32.0
Costa Rica	7.1	10.7	10.6	11.5	34.4

Source: Philip H. Coombs. *The World Educational Crisis. A System Analysis.* Table 5, p. 72, New York, N.Y., Oxford University Press, 1968.

The students are required to opt for a concentration on either art subjects or science subjects in the pre-final year of secondary school.

This subject distribution is typically true for general secondary education. For vocational secondary education the basic subjects are the same in the junior grades at this level while special technical skills are allotted increasing percentages of the total contact time with the maximum percentage being allotted in the final year. The pattern of training is markedly dependent on whether the vocational school is urban or rural. Urban schools impart training in mechanical and electrical engineering, engineering drawing, etc., while rural schools focus on subjects like agricultural machinery and cattle-breeding.

Our response to the question 'Where are we now?' has thus far been extremely general. From it we conclude that the decision makers face certain quantitative problems such as those of increasing the public expenditure on education, decreasing the ratio of pupils to teachers, and increasing the number of pupils who will reach institutions of higher learning, implying, of course, a diminution of wastage. It is clear that broad socio-economic problems have to be solved including the overwhelming one of overpopulation.

But we have not yet looked into the qualitative details of how science is taught and how it may be improved through innovation. The object of such an exercise would be to find out how present systems differ from the projected goals of Chapter 2. This difference

could then be used to generate an 'error signal' to steer reform into a desirable course in the same way that the difference between the real temperature in a room and the thermostat setting generates an electrical impulse that turns on either the heater or the cooler in an attempt to bring the real temperature closer to the desired one.

An examination of qualitative details would be very difficult to carry out for the whole world or even for the developing world because of the great differences between countries. But it would be a meaningful exercise for the educational planners of any given country because they know or can find out just where they stand relative to the ideals discussed in Chapter 2.

I suggest, therefore, that this be done as an exercise by science educators and planners in the different countries. Instead of discussing here each of the eighteen points of Chapter 2, pages 51-3, I suggest you turn back to that section and ask yourself how the system in your country would rate on each of those points. I feel certain that you will find it illuminating even if you do not attempt to make it quantitative, although it can be made quantitative. I shall propose one method of doing so but the reader can, I am sure, invent other ways.

Consider, for example, the paragraph which reads: 'A large classroom with plenty of fresh air and light and adequate control over temperature, humidity and noise level.'

I have visited classrooms in many developing countries and they would score high on some parts of this paragraph and low on others. In a country where the weather permitted having continuously open windows I was once giving a lecture when a rainstorm of major proportions broke loose. Because the roof was of metal the noise level rose so high that no one could be heard. Thus, although there was plenty of fresh air, there was also an abundance of noise and a high humidity, factors which can adversely affect the teaching-learning situation. I would have given this school a rating of 3 out of 10.

To make your own judgement quantitative try to assign a number from zero (very inadequate) to 10 (perfect) for each paragraph. You will, of course, immediately run into wide variations with regard to the point in question even within a small country and may wish to divide the schools into, say, urban and rural. Regardless of how you go about it, I believe that although different observers would assign different scores to a given paragraph the scores will cluster around zero if the system is very poor and around ten if it is excellent.

Consider another paragraph, for example:

> a well-trained teacher, in good health, not too overloaded with work, alert to the individual needs of students, not authoritarian, permitting class discussion, sensitive and proud of his or her task which is not simply to dispense the facts of science but *to create an environment in which learning can take place.*

It is a rather complex paragraph and could easily have been broken down into several parts each of which could be graded separately. But even if left as it is, an over-all evaluation could be made by those who are acquainted with the system and a score within the limits of zero to ten could be assigned.

There are eighteen paragraphs in the check list so that the maximum total score would be 180 points. Few, if any, school systems, even in the most advanced countries, would score anywhere near 180 points. A rough estimate for the schools in my neighbourhood in California yielded a score of 125 points. Within the most highly industrialized countries there would be some schools that would rate very low indeed.

I do not wish to suggest that the procedure I outline above for scoring is the result of research into the methods of evaluation. It is not. I do believe, however, that if a concerned reader were conscientiously to score the systems of his own country on the basis of this list, he would have generated some sort of an error signal that would give him a clue as to how to put reform on the right course. It would certainly suggest some areas that need immediate attention.

After we discuss, in subsequent chapters, the approaches to reform that have already been tried, we may be in a better position to return to our check list and decide what priorities should be assigned to the different paragraphs to correct the faults we have found and what particular actions might be appropriate.

The need for qualitative changes in science education

If we assume that improved science and technology education are important for economic and social development it seems indisputable that quantitative improvements in science education systems are required. Especially in the developing countries, more of everything seems to be needed; more teachers, classrooms, school buildings, laboratories, books and teaching aids. More children should have the opportunity of staying in school beyond the fourth grade. More pupils should have access to secondary and higher education.

A need for quantitative expansion would hold even if the population were static and if science and technology stood still. More schools, for example, would at least give more children access to the science education which is now available, inadequate as it may be.

The quantitative demands of the real world, however, are considerably greater than those needed for a hypothetical static

population. Population is exploding, as we know, especially in the regions of the world that are least developed. It can quadruple in a man's lifetime.

The qualitative standards suggested by the check list discussed above, on the other hand, would hardly be improved at all by simply having more of what we now have. If you read through the check list of Chapter 2 again you will see that a score based on it would increase more by qualitative changes than by quantitative ones.

Scientific and technological knowledge and information, however, are not static either. By almost any measure that has been devised they are doubling about once every eight years or by a factor of 500 in a man's lifetime. This implies, of course, that the subject matter of science is changing and hence that textbooks, syllabuses and curricula must also change. Proliferation of knowledge that is not up to date would lead to deterioration rather than improvement in science education.

We conclude that both quantitative and qualitative changes are needed. Which will really yield the greater improvements? The educational decision makers would like to know that, but we are not prepared to give a simple answer. The answer will depend upon the particular needs of a country and the formulation of these needs by the decision makers will require a clear statement of goals and objectives. It will require using the techniques of systems analysis to be discussed in a later chapter, in which the effectiveness of the system will be judged on whether the output of the system, in this case the graduates, possesses the characteristics and capabilities that were planned for.

At the moment, it does not seem likely that even the quantitative demands of the future, especially in the developing countries, will be met. The race between an exploding population and the mad rush to build more schools and train more teachers seems likely to be won, hands down, by population.

Is there some hope, then, that some dramatic qualitative breakthrough is imminent that might save the day? I feel pessimistic about this, too. Perhaps completely new systems have to be devised. Perhaps changes which might be characterized as 'radical' or 'revolutionary' will be needed. Perhaps the critics of schooling, like Ivan Illych, who say that we will never really educate children through schooling, have to be listened to in spite of the fact that they do not yet seem to offer viable alternatives. Perhaps Ul Haq is right when he contends that much more direct means must be found to assist those who need help the most—the poor of this world. Perhaps what we really need are imaginative and viable schemes to have learning of science and technology take place 'where the action is'—on the farm, in the shop, in the home and in the field. We are not prepared to say which of these courses should be taken. What does seem clear is that 'more of the same' will not solve the problem.

Reform and innovation as continuing needs

Because continuous and accelerated change seems to be the most important characteristic of our times, reform and innovation must be planned on a continuing basis. No 'one shot' solution has yet been found nor is it likely that one will be found. If institutions are created to promote innovation they will be effective to the extent that they are flexible and can adapt to and help modify the changing needs of society.

The special needs of the developing countries

We saw earlier that the basic characteristic of developing countries is poverty. Innovative schemes that worked well in affluent countries are likely to fail in the developing countries. The challenge is for imaginative thinking and the invention of new solutions that stand a chance of working in spite of very limited means. Here again, the goals set for science education play an important role. If the goal is only to produce the necessary number of scientists and technologists required by a manpower projection based on the assumption that the country will develop after the pattern of existing industrialized societies, then the course of action is relatively clear, even if difficult to achieve. The probability of the present developing countries ending up as replicas of existing industrialized countries is very low indeed. If, on the other hand, the decision makers decide that one of the aims of science and technology education is to create in all pupils a set of behaviour patterns that can be useful to them throughout their lives regardless of their occupation, then other types of educational schemes will have to be developed. They need not be expensive. My hope is that the students that emerge from such improved systems will be inspired with the creativity of the scientist and the kind of competence associated with the problem-solving approach of the engineer and the technologist.

Part II
Past experience and present trends—the winds of change

4

What has been learned from recent efforts to improve science education?

In terms of our hypothetical travel through the land of science education improvement we are ready to ask 'what have we learned about making such a journey?' One of the important lessons has been that it requires innovation. Just what does the term mean? How does it get started? Can innovation be planned? These are some of the questions we will now consider.

Innovation and improvement

At a Unesco regional seminar [88] on science improvement in Latin America in 1972 the following opinion was expressed:

> Two roads are open for innovation: to propose changes by way of the intuitive approach that has been employed to date, based on the opinion and the authority of those who are considered experts, or to treat the problem with a more scientific approach . . . that is, *to treat innovation as a technological process.*

This is an interesting idea which is cropping up in many different places round the world a little more than ten years after the first wave of reform projects got started. Let us first look into the innovative process in general in search of insights that might apply to innovation in science education.

The innovative process

In a very interesting report prepared for the National Science Foundation entitled *Interactions of Science and Technology in the Innovative*

Process: Some Case Studies [18], hereafter called simply the NSF report, the diverse ways in which research and development activities support each other in the innovative process are considered. Four of the eight technological case studies, for example, were devoted to the video tape recorder, the heart pacemaker, electrophotography (xerography), and oral contraceptives. The report begins with a definition.

> [*Innovation*] A technical innovation is a complex activity which proceeds from the conception of a new idea (as a means of solving a problem) to a solution of the problem, and then to the actual utilization of a new item of economic or social value.
>
> Innovation should be distinguished from scientific discovery, which involves the observation of a previously unknown or unobserved phenomenon or the acquisition of new knowledge; although relevant discoveries may be incorporated into the innovation. Innovation should also be distinguished from invention, which is the creation of a novel product or process, or a concept of a means of satisfying a need. The invention, however, may provide the initial concept leading to innovation. Finally, innovation must be differentiated from diffusion of technology, which is the evolutionary process of replacement of an old technology by a newer one.

In science education the final product, as it deals with human beings, is much more complex than a video tape recorder or a heart pacemaker but the above definition seems to be applicable.

More generally, then, and with less precision, innovation is the complex process of putting new ideas into practice. The new ideas arise from invention—the process of conception. An innovator, according to this definition, has to be an entrepreneur. We will see that some of the people who helped start the recent wave of reform in science education were innovators in this broad sense.

To illustrate the steps including invention, reduction to practice, the search for technical and financial support, development and diffusion, I shall summarize briefly the fascinating account concerning electrophotography given in the NSF report.

Electrophotography has become widely known because of the great success of the commercially produced Xerox machine. The Xerox 914 Copier, the first automatic electrostatic photocopier, has been described as the most successful single product ever marketed and as satisfying a need whose magnitude was far in excess of initial expectations.

There is little question of the major impact of this innovation upon the business world, and upon communications generally. On a volume basis alone, the effect is impressive. Within a few years following introduction of the first copier, the number of copies of letters and documents made in the United States rose from some 25 million in the mid-fifties to 9.5 in 1964, and to 14 billion in 1966, not to mention billions more outside the United States. The

availability of multiple copies of documents has caused a significant change in the methods of communication in the business world, in government, throughout the fields of education and technology, and among the public in general.

The inventor of electrophotography was Chester F. Carlson, a patent attorney who, in 1935, became aware of the need for a more efficient copying process. In 1937, influenced by Selenyi's work, Carlson conceived of a way in which a light image could be converted into an electrostatic image on a photoconductive layer and then proceeded to make it visible. The basic concept was to impress the electrostatic image on the charged surface of a photoconductor, an idea which had evolved from an appreciation of Selnyi's invention.

Early in 1939, Carlson filed a patent application and began his attempts to interest some company in taking over the invention. Those he contacted were generally in the fields of business machines, office equipment, instrumentation and photographic equipment. He was unable to impress management with his crude demonstration or to instil the technical staff with enthusiasm for the potential of the process or the feasibility of its engineering development. After some years of further development work, the first public demonstration of the process was conducted in 1948.

By carefully listing and evaluating what they define as significant events and decisive events in the progress of innovation in this and seven other such cases, the authors of the National Science Foundation report came to the conclusion that, while innovation cannot be completely controlled, programmed or planned, it can be helped along by management if they are willing to promote it by permitting and encouraging innovators to act upon ideas that fall outside the established or recognized patterns.

For innovation to succeed, they contend, four conclusions stand out: (a) the technical entrepreneur is an important—perhaps the most important—driving force behind innovation; (b) recognition of a technical opportunity and a recognition of the technical need to be fulfilled, both rank high; (c) funding is important; (d) confluence of technology, unplanned in most cases, was important to all case histories, and to a substantial number of decisive events.

Other studies by Price and Bass [19] of the role of scientific research in the innovative process confirm the idea developed in the above report that while many innovations are based on scientific knowledge, innovation does not usually proceed in an orderly 'linear' way from the discovery of new knowledge through invention, development and eventual emergence as a final viable product. In fact, it seems to be true that the more novel the invention, the less orderly and predictable is the innovative process. An analysis of several studies on innovation led Price and Bass to three conclusions:

Although the discovery of new knowledge is not the typical starting point for the innovative process, very frequently interaction with

new knowledge or with persons actively engaged in scientific research is essential.

Innovation typically depends on information for which the requirement cannot be anticipated in definitive terms and therefore cannot be programmed in advance; instead, key information is often provided through unrelated research. The process is facilitated by a great deal of freedom and flexibility in communication across organizational, geographical and disciplinary lines.

The function of basic research in the innovative process can often be described as meaningful dialogue between the scientific and the technological communities. The entrepreneurs for the innovative process usually belong to the latter sector.

Innovation in science education

There have been many innovative projects in science education since the mid-1950s and some retrospective studies and evaluations have been made of them; but, to the best of my knowledge, no detailed study of case histories from the point of view of the innovative process in science education analogous to that of the NSF report has been made. It would be useful, of course. It would also be difficult and possibly costly but not impossible.

In a paper entitled 'The Design of New Courses' which I prepared as a working paper for the 1972 Unesco Regional Seminar on Science Education Improvement in Latin America I dealt with four case studies. They were all courses in physics or at least with a physics component, designed to improve the teaching-learning situation. My involvement with each of them ranged from superficial to total at least for a limited interval of time. They were: (a) the physics course of the Physical Science Study Committee (PSSC) originally at the Massachusetts Institute of Technology; (b) the Unesco Physics Pilot Project; (c) Project Physics of Harvard University; and (d) the Science Foundation Course of the Open University of the United Kingdom.

Some of the details in that paper will be discussed later. What is relevant at this moment is the fact that it ended with a check list of guidelines for innovation which emerged from a study and analysis of these projects. It was not a comprehensive study like that of the NSF report but I shall list five of the guidelines here because, having been developed quite independently, they bear out some of the conclusions of the NSF report.

There must be something inadequate in the existing courses which prompts an individual or a group to do something about changing it. Someone must be sufficiently motivated with a desire for change and improvement to take the initiatives necessary to get it started.

Innovation often requires a visionary pioneer who is willing to take

the leap into the unknown with incomplete knowledge of what the final product will be but with a drive that leads him on in the process of design.

The effort will have to involve a team and the leader must be able, by virtue of his personality, his position, or his talents to attract a group of knowledgeable and enthusiastic followers.

Projects of this sort require financial assistance. In the case of the Open University, for example, it had to be massive. In the past it has been possible to obtain support from private sources, but as the projects become more involved it will probably be necessary to tap government support. Some may require support from international agencies.

No matter how high the quality of the materials produced by a course team, it will not be used on a large scale within most countries unless it has the academic approval and financial support of the ministry of education or some other governmental agency, depending upon the nature and the level of the course. It is well, therefore, to seek this kind of support at the outset. The innovators can dream up the new ideas but they will never be implemented on a large scale without the approval of the decision makers who hold the power of implementation in their hands.

We find some similarities and some differences as we compare these five points with the four conclusions of the NSF report. On four important ideas there is convergence: (a) the importance of the recognition of a real need; (b) the importance of the entrepreneur who often pushes ahead because of a faith in his idea despite opposition or apathy; (c) the need for support, financial and administrative; and (d) the importance of diffusion. The 'confluence of technology' of point (d) of the NSF report has a parallel in the appearance of modern educational technology in the science education projects. This will be discussed in a later section.

Invention and innovation are not synonymous with improvement although they are often motivated by a desire for it. In science education it is, of course, important to decide which of the many felt needs are the most important to motivate innovation aimed at improvement. To those about to embark on a programme of science education improvement I would suggest a careful re-reading of the check list in Chapter 2 for suggestions on what the needs really are. An innovator, reading this list, may be sparked to follow up on one or more of its points in the same way that Carlson was stimulated to work on electrophotography.

It is said about another innovator, Charles Hall, who invented the electrolytic method of extracting aluminium from its ore, that he was stimulated by a chance remark once made by his chemistry professor at college. The professor said that anyone who invented such a process would become both rich and famous. Hall became both

because he was not only an inventor but an entrepreneur; in other words, an innovator. In the science education field the innovator cannot be promised either riches or fame, although they might follow, but he would be working in a field where the needs are enormous. There would at least be a great personal satisfaction awaiting those who contribute to satisfy these needs.

What prompted the reform movement that began in the 1950s?

After the Second World War, during which technology had played such an important role, scientists in the advanced countries of the West were shocked to find that their children's science textbooks had not changed appreciably since the turn of the century (I will deal here primarily with the causes of reform in the West. Some conjectures about what may have been happening in Eastern Europe at the same time are made at the end of this section). Their content was no longer representative of the views of the scientific community. The physicists, in particular, were concerned because physics textbooks had come to give more and more attention to technology, thus minimizing the concepts and unity of science itself.

The initiative for change was taken by university scientists. They broke with their traditional non-involvement in secondary education. (I shall subsequently, however, show that in the United States, at least, university scientists used to write secondary school science textbooks in the late 1800s.) They became vigourously active in reform. As they looked further into school education they found that science was still being taught in an authoritarian manner and dispensed as a set of stable facts to be memorized in rote fashion by students and handed back during examinations. They found that the excitement of discovery, so characteristic of science, was missing and that teachers were poorly prepared. There was a minimum of 'hands-on' experimentation by the students and a dearth of relatively inexpensive laboratory materials that could be used by the students themselves. There was considerable reliance on chalk-and-talk presentations and very little use of the newer audio and visual learning aids.

In the light of what we said earlier about innovation, the first requirement—a felt need—was there in abundance. The second

requirement—the pioneer and entrepreneur—began to appear among the scientists in the early 1950s. In Brazil, in fact, Isaias Raw had, as early as 1949, already started to publish a journal called *Cultus*, devoted to innovation in science education, and through his continued efforts in the fifties and sixties made Brazil perhaps the most active Latin American country in curriculum reform. The third requirement —funding—began to flow, at least in the United States, through the National Science Foundation and other agencies, also in the mid-1950s.

Special credit must be given to the pioneering efforts of the PSSC headed by Professor Jerrolda Zacharias of the Massachusetts Institute of Technology for his role as scientist and entrepreneur in the curriculum reform. Mainly through his efforts the National Science Foundation made an initial grant of $300,000 in November 1956 and the full-scale activity of PSSC was able to start. This was just the beginning; more will be said about PSSC later but we may quote from the summary of its first report two goals which were to guide not only the PSSC but the whole reform movement for some time.

> The first of these goals has already been mentioned: it is to restore the primacy of subject matter in the educational process. We have all but forgotten, in recent years, that the verb 'to learn' is transitive. It must have an object; there must be something or things that the student learns. . . .
>
> Next, we wish to transfer the responsibility for the learning process from the teacher to the student. In the end, nothing that is worth knowing can be transmitted in a one-way flow teacher to student. It must be learned by the student, and the proper function of the teacher is to create conditions under which such learning is possible and likely.

What prompted the reform movement, then, was what prompts innovation in general; the felt need, the emergence of the entrepreneur and his ability to find financial support.

The effect of the launching of the first orbiting satellite by the U.S.S.R. in 1957 cannot be minimized. Sputnik did not launch the science teaching reform in the West—it had already started—nor did it change its course, but it certainly helped to loosen government and private purse strings in the United States for financial support on a scale previously unmatched. This was to have world-wide repercussions, as we shall see.

The United States reaction to Sputnik varied greatly. Scientists, by and large, commended their Soviet fellow scientists and engineers for their achievement but the public reaction was one of apprehension, born of distrust in a cold war atmosphere. Motivated by a desire to stay ahead in the technological race, linked with efforts to strengthen the economic and defence position, legislators were willing to bolster science since they had been led to believe that it was the fountainhead of technology.

Daniel V. De Simone in a book entitled *Education for Innova-*

tion [20] has made an interesting observation concerning the orbiting of the first man-made satellite of the earth by the Soviet Union:

> Although this was a spectacular feat of engineering innovation, which caused tremors in American educational circles strangely enough it was hailed in this country as a 'scientific' miracle and the educational reforms thereby generated in American engineering schools were *science*-oriented. (It is true that the scientific principles upon which Sputnik was based were, as we said earlier, in some cases over two hundred years old.)

Science education, then, and not engineering education profited most from the dramatic impact of Sputnik.

Gatewood and Obourne [21] say:

> By the 1950s the stage was set; the time was ripe for reforms in science education in the United States. When Sputnik launched the space age in 1957, everyone was ready to do something, even if it was wrong. Parents, children, professors and politicians tried to partake of this popular new dish called Science.

They also make the interesting point that the non-involvement of scientists in secondary school science education in the 1940s had not always been traditional. There was a time, in the late 1870s, when university professors wrote the texts and gave rather close attention to the quality of school curricula, patterning them after their own courses. During 1910 to 1930, when the high school population of the United States was increasing by a factor of four, university professors became preoccupied with their own endeavours and paid less and less attention to secondary education. Control was not wrested from the university professors but rather was assumed by the secondary school teachers by default. From 1925 to 1950 school science textbooks were written largely by high school teachers, often with the assistance of a professor of science or science education. Emphasis was on factual information that would allow the overworked teacher to administer and grade tests with the least possible effort.

It was at this point that the university professors, some of them returning to academic life after years of development work for the military establishment, began to assume responsibility for content in the secondary school curricula once again.

Although this analysis of what prompted reform is based upon experience in the United States, my contacts in other countries during the 1960s lead me to believe that it was almost universally valid. What was wrong with science education in the United States was, in varying degrees, the same as what was wrong with it in other countries. My observations in Latin America and the United Kingdom substantiate this view. Information gathered through Unesco about Asia, Africa and the Arab States also confirm this.

The situation in Eastern Europe is harder to assess. These countries have traditionally left reform in the hands of their highly centralized pedagogical institutes and so probably did not experience —and possibly did not need—the kind of massive effort at modernization that was needed elsewhere. No doubt they, too, had to cope with the explosions in information and school populations but they probably did it according to a different pattern.

As we said earlier, the ability to launch a Sputnik is an indication of achievement of a high order in engineering and technology, not necessarily in science. But the high level of sophistication of the technology used in this case is a strong indicator that it was built on a solid base of modern science. Did this also indicate superior science education? Did the Soviet Union ever launch anything like the massive reform movement of the West? Had their scientists also observed an inadequacy in their high school science textbooks and had they become involved in promoting a reform which led to improved science, which in turn led, in linear fashion, to the improved technology which produced Sputnik?

These are questions to which I do not have clear answers in spite of having worked with Soviet colleagues in Unesco and visited the U.S.S.R. and other Eastern European countries several times during the sixties. I can only give my impression which is that they did not experience the same kind of discontinuity and upward thrust in curriculum reform that the West did. Perhaps their system of leaving continuous reform in the hands of university-level scientists and educators in the pedagogical institutes produced, in a continuous manner, the necessary improvement in approaches, methods, materials and techniques which had required a discontinuous massive attack in the West.

The high level of achievement in technology in the Soviet Union may have been due to another reason. In the U.S.S.R., as in other Eastern European countries, all students in secondary school take courses in physics, chemistry, biology and mathematics, each for four consecutive years in contrast to the one-year courses given in the United States to a selected fraction of the student body. My theory holds that by building on such a large statistical base of a highly motivated student population, using traditional methods and spreading the learning out over several years, they were able, by picking the cream of the crop, to generate enough high-level scientists, engineers and technologists to produce not only the Sputniks but the whole range of electronics, rocket propulsion and other gear associated with the space programme and to compete successfully with the United States.

It is unfortunate that the relative merits of the different approaches to science and technology education improvement characteristic of the East and the West have not yet been discussed in the open forum of an international conference because all the countries

could stand to gain from such an interchange—especially the countries of the developing world.

Concerning China, which represents such a large fraction of the world's population, I can, unfortunately, say nothing as regards science education. Perhaps now that China is a member of the United Nations and of Unesco it will be possible to have its scientists and educators participate in the interchange of ideas on the subject of innovation in science education.

The characteristics of some early innovative projects

Pioneering efforts in the United States

Not long after the end of the Second World War, the need to reform science education was felt in all countries of the world more or less simultaneously. My direct knowledge of the response to this need is, unfortunately, limited almost entirely to countries outside Eastern Europe and China. I shall, nevertheless, later describe some of the observations I made on a trip to the U.S.S.R. for the purpose of studying this question in 1969 and other facts about science education in Eastern Europe learned through Unesco. I shall try to avoid the natural tendency to look at the world problem through the eyes of a United States citizen who first became involved in science education reform in the early days of PSSC. My experience, fortunately, has not been limited to the United States. My horizons broadened considerably when I joined Unesco in 1961 and have remained globally oriented ever since. My work for the United Nations Advisory Committee on the Application of Science and Technology to Development and for the Committee on the Teaching of Science of the International Council of Scientific Unions (ICSU) since its reconstitution in 1969 has permitted me to continue to look at the problem from a world-wide point of view.

My approach will, of necessity, be synoptic. I have not had the help of the research team which would have been needed to study the global problem in depth. In spite of this, it is hoped that the informed opinion of one person will be of interest and possible help to the future innovators in science education.

It is probably fair to say that although many projects in the 1950s were started independently of one another in different countries of the world, the sheer magnitude of the United States projects produced a catalytic or reinforcing effect which was felt round the world. There were marked differences between the projects, depending on the subject matter and country of origin, but one can also discern some similarities. The following is an attempt to summarize the characteristics that applied to most of them.

They were team efforts in which outstanding scientists often played the role of entrepreneurs and leaders. (At one time, ten Nobel Prize winners were involved.) They enlisted the help of scholars and other members of the educational community such as teachers, psychologists, administrators and people with special talents bearing on the educational enterprise.

They were content oriented; that is, they began by deciding what new subject matter should be introduced and what should be deleted. As we said earlier, a primary goal was to restore the primacy of subject matter in the educational process. Scientists—who were the subject matter specialists—played a fundamental role in rethinking both content and approaches. An attempt was made to have the content reflect the structure of the discipline itself.

The projects were usually discipline centred; that is, they stayed within the traditional boundaries of physics, chemistry, biology and mathematics. The soul-searching that took place began to reveal that some of the boundaries between the disciplines are artificial and should be crossed or torn down, anticipating the emphasis that would be given in later projects to interdisciplinary and integrated approaches.

They attempted to present the sciences as systems of inquiry rather than as stable bodies of knowledge. They de-emphasized rote learning and promoted, instead, active participation and discovery on the part of the student. They stressed the importance of asking questions to which the now time-worn title of 'inquiry approach' was given. They also stressed major conceptual schemes and basic concepts in the choice of which research scientists obviously played an important role.

Great emphasis was placed on having students come to grips with phenomena directly through new laboratory and field experiences in which the students were encouraged to discover ideas for themselves rather than merely verify previously stated principles. They were stimulated to investigate in the same spirit and with the same approaches used by scientists; all of this in an attempt to transfer the responsibility for the learning process from the teacher to the student.

They developed new materials for learning and teaching. The exercise usually began with the writing of a new textbook in order to

get the content and order of presentation right. The development of inexpensive laboratory apparatus, audio and visual materials, teacher guides, evaluation and testing materials, and supplementary reading matter then followed in a logical fashion. Some projects placed great emphasis on the use of film and television to augment the significant phenomena that could be brought into the classroom.

Since the projects based on new materials could not succeed without teachers who were trained to use them, programmes (institutes) for pre-service and in-service training of teachers were launched with materials specially prepared for them.

Serious attempts were made to try out the new materials and approaches in the classroom with trial versions. The final versions incorporated changes that arose out of these trials. The feedback obtained from students improved the presentation by making it more readily understandable.

The projects started at the secondary level but very soon stimulated activities at the primary level and have since motivated changes in college science curricula.

The characteristics listed above applied more or less generally to the five projects—sometimes called the first generation projects—funded, in great part, by the National Science Foundation of the United States. During the eight-year period 1952–60 the foundation spent $13.5 million on course content improvement. Their efforts to improve the teaching of science and mathematics had widespread appeal. In the 1957 budget, possibly reflecting the influence of the launching of the first Sputnik, Congress included $5 million more for this purpose than the foundation has requested! By 1966, the foundation was allocating $16 million for one year alone, for course content improvement in science education at all levels. Of even greater importance, probably, was the fact that it was also spending another $113 million on supplementary programmes including fellowships, institutes for teacher training and other special activities for teachers and students in science education.

The original projects, with the date of publication of the first commercial edition of their materials were: (a) the Physical Science Study Committee (PSSC), 1960; (b) the School Mathematics Study Group (SMSG), 1960; (c) the Chemical Bond Approach (CBAP), 1963; (d) the Chemical Education Material Study (CHEMS), 1963; (e) the Biological Sciences Curriculum Study (BSCS), 1963.

By 1963–65 it was estimated that the following numbers of students were using materials from these projects (figures in parentheses show the percentage of those studying the subject who were using project materials): PSSC, 200,000 (50 per cent); SMSG, 1,350,000 (10 per cent); CBAP, 50,000 (4.8 per cent); CHEMS, 210,000 (2 per cent); BSCS, 580,000 (20 per cent).

Space does not permit us to give details of the output of these

projects. They may be found in references [21], [22] and [23]. We do not want to give the impression that they were the first to get started, nor that the National Science Foundation was the only source of support for the movement. (The University of Illinois Committee on School Mathematic began in 1951. Its success probably gave credibility to the idea of reform.) Other government agencies, state departments of education, local school systems, professional organizations, private foundations and colleges and universities all made significant inputs. The massive support of the National Science Foundation, however, exemplified the urgency with which the problem was tackled and the level of interest and support it attracted.

The movement for reform grew and extended itself to other parts of the world as we shall see. By 1972 there were at least 120 different projects in the United States. These are listed in the *Eighth Report on the International Clearinghouse on Science and Mathematics Curricular Developments, 1972* [24] to which the reader is referred for details on these and other projects. This publication is the most comprehensive source of information on science education improvement projects in the United States. Objectives, history, materials produced, support and evaluation are among the topics summarized for each project. Within its 858 pages there is also much information on similar projects in other countries.

Before concluding this very sketchy summary of the earliest projects in the United States it should be observed that by around 1963 some of the inadequacies of the first-generation projects were beginning to be recognized and solutions proposed. In other words, new 'felt needs' began to motivate a new round of entrepreneurs to invent and promote their innovations. Of great concern, for example, was the fact that in spite of the efforts of the PSSC group, enrolment in high school physics courses was declining. A suspicion began to develop that the PSSC programme, although excellent for the scientifically gifted student, was too difficult or possibly just not suitable for the average student and the one with little interest or ability in science. In addition, there was a growing feeling that the projects were too strongly single-discipline oriented. We should not forget, incidentally, that world events had sparked a student revolt which drastically affected trends in education as a whole and engendered a feeling of alienation towards science, making it difficult to measure whether the existence of science curriculum reform projects had had any influence at all.

The critics of the PSSC course, besides noting declining enrolments, lamented the fact that the massive effort in physics had all gone into one course rather than into several different and simultaneous approaches by separate groups. There were two different groups in chemistry (CBAP and CHEMS) and the BSCS produced three entirely different versions of their materials. In mathematics there were other groups besides SMSG working on different approaches

(the University of Illinois Committee on School Mathematics has already been mentioned but there were several others). The reason for promoting more than one approach was the fundamental idea, adhered to by the National Science Foundation, that there is probably no single best way but possibly several good ways to improve instruction in science.

Only in physics was there initially just one large project. It was natural, therefore, that other physics innovators with different ideas should come along. Among these was Professor G. Holton of the Department of Physics at Harvard University who noted that only about 4 per cent of the senior classes in United States high schools were attracted to the PSSC course. Against a background of a constantly dropping fraction of students taking any high school physics at all he formed a team of scholars and other specialists to generate a new course to overcome the deficiencies of previous efforts. In 1963 the National Science Foundation called a meeting of interested physicists out of which arose a request to the directors of Harvard Project Physics to convert their initial work into a national curriculum project.

The Project Physics Course (PPC), as it came to be known, was characterized by a humanistic orientation. It followed the precept that a good introductory course can use the history and social consequences of science as teaching aids without causing physics to yield its claim as an important discipline of primary importance. This project also pointed the way towards integration of the subject matter of physics with other disciplines, and showed a concern for the international use of their materials and for the concept of the social responsibility of the scientist who helps plan the course and of the student who will later take his place in society.

Other departures included greater participation on the part of teachers in developing the course; flexibility that permitted the teacher to choose from a wide range of materials of different kinds and thus create, within limits, his own course; a new emphasis on evaluation, with the help of competent scholars, of the course and of the achievements of the students; and greater diversity in the range of learning aids produced, including new visual aids and programmed learning sequences.

Another example of a second-generation effort was the Earth Science Curriculum Program (ESCP). The major characteristic of this programme was its multidisciplinary nature, involving physics, chemistry and biology as well as geology. Because the ESCP was intended primarily for the pre-secondary school level, it illustrated two important trends: (a) a shift in emphasis in the reform movement towards the elementary grades, and (b) the integrated teaching of the sciences. It also responded to the growing recognition that children can learn more than we usually give them credit for, that curriculum planning will eventually require not only the integration of the

different sciences but also the integration of the sciences with other school subjects.

We can hardly claim to have done justice to the vigour of the second wave of curriculum reform in the United States in the 1960s by discussing only two of the National Science Foundation projects, but we must move on to consider what was happening in the rest of the world. A National Science Foundation survey carried out in 1967 lists twenty-eight major projects in pre-university science education and a report published in 1970 lists seventy-two in this category. They range from kindergarten to the twelfth grade and include new topics such as social studies, social sciences, technology, astronomy, computers, physical science and interdisciplinary courses. And, as we implied earlier, there were almost as many other projects funded by agencies other than the National Science Foundation.

During the 1960s projects were also springing up in other parts of the world, in some cases animated by the success of projects in the United States. Before discussing these, we shall try to characterize the second generation movement in the United States as a whole, knowing full well that this is a difficult job considering the diversity of the projects.

With this caveat we quote below excerpts from a summary of trends in the 1960s written in 1969 [25]:

> The leadership still included the scientists, but not so exclusively. A closer collaboration began to be effected between educators, teachers and the scientists. Although the earlier projects had been forced to recognize the importance of retraining teachers, since the program could not run without them, the importance of having the enthusiastic support and approval of science supervisors, teacher trainers and practising teachers forced the new projects to work more closely than ever before with scholars and administrators in education. Psychologists began to make more of a contribution, especially those in the fields of learning theory and behavioral technology.

As might be expected in a second round, a reappraisal was made of objectives and target populations. It was felt that the original projects, although they had claimed to cater for the student in general education as well as for the future specialist in science, had in fact satisfied very well the needs of the élite who would go on to specialize in science but had left many students of average capabilities in science and the great majority of students who had no interest at all in science inadequately served. Hence there was a tendency to broaden the target population first by including those at the secondary school level who had no intention of specializing in one of the subject areas—including some very gifted people in the arts and humanities—and subsequently to move both down to the elementary grades and up to the university level where the need for improvement was being felt, partly because some of the high school students enrolling were coming in better prepared than they had been in the past.

Such terms as 'social commitment in science' and 'humanistic education' began to appear more often in the description of the objectives of the new projects. The adjective 'behavioural' began to appear as a modifier to the term 'objective'. Those who had at first objected to the introduction of the jargon of behavioural technology which included phrases like 'terminal behaviour' and 'target population' were soon appeased when they learned that these phrases helped clarify the idea that in preparing teaching materials one should state clearly, and possibly in quantitative terms, the qualifications of those one intended to teach and should state in advance what one wanted them to be able to do ('behavioural objective') at the end of the course which they were not able to do before taking it.

All of this had a healthy effect in stressing that learning was the ultimate objective of teaching. That being the case, since it could be demonstrated that students were able of learn certain kinds of facts and some behaviour patterns with proper self-instructional aids, even without a teacher, it opened up the possibility that the teacher shortage might be relieved with the proper kinds of aids for auto-instruction.

Great emphasis began to be placed on the notion that science has a liberating and liberalizing influence and should properly take its place among the humanities. The target population soon covered the academic range from elementary school to the university and it began to reach out to the underprivileged groups within the advanced nations and to the pupils of other countries through programmes of bilateral assistance.

One of the important trends as regards content was the increased variety of resource materials that were put at the disposal of the teacher so that he could fashion from them a course which he could more readily feel was his own. The variety also extended to the choice given to the students. This catering to individuality and individual differences was, in effect, an expression of the idea that the broad human needs of the teachers and students had to be met.

One heard less about inquiry and discovery and more about 'process' since, it was claimed, science is both a 'product' and a 'process' and we benefit from both in our daily lives.

The new projects and the whole movement began to be characterized by a broadening of interest—first by acknowledging the need for experimental courses of an integrated nature, second by considering more carefully how the science courses were to fit into the over-all curriculum, third by recognizing that curriculum reform is not a 'one-shot affair' but has to be implemented on a continuing basis. Science teaching centres began appearing whose function was, among others, to carry on the kind of research and development work that had been done in one subject at a time in the old projects but now would be done with all the basic sciences and mathematics undergoing continuous reform, possibly integrated and sometimes under one roof. The term 'rolling reform' was coined and applied

to this process of continuous upgrading of contents, approaches, methods, teachers and materials. All of these trends required a closer collaboration among scientists, educators and specialists in psychology and communication.

An international demand for translations and adaptations of the United States materials began soon after they first appeared. The leaders of the reform projects in the United States discovered that they had developed products for which there was global hunger. Some of them advocated, with almost missionary zeal, the immediate translation of existing materials. Others leaned more toward adaptation of materials by indigenous teams in the different countries. Both were tried and some appraisal of their success in both developing and advanced countries will be given below. Let us now consider briefly what was happening in other parts of the world.

Science teaching reform in Western Europe

At the beginning of the twentieth century, leadership in science and technology belonged to Western Europe but by the end of the Second World War it had shifted to the United States and the Soviet Union. It was in keeping with their growing need for science and technology that both countries mounted programmes for the reform of science education. It soon became obvious, however, that if these new leaders in science felt the need for improvement, the countries of Western Europe were in need of reform as well.

The concern for improvement of science education in Western Europe arose among the science teachers themselves and did not depend quite so much on the initiative of scientists as it had in the United States. One reason for this may have been that the secondary school science teachers of Europe had a higher academic level than their counterparts in the United States. This resulted in a sense of professionalism and status among them that was missing in the United States. Active professional teaching associations in Western Europe, for example, frequently organized *ad hoc* committees to consider the problems posed by the need for reform. Another reason why teachers rather than scientists initiated reforms may have been that university scientists in Europe had, by tradition, such a high intellectual and social status that they did not feel at ease becoming involved in the seemingly humble task of elementary and secondary science teaching reform.

Most Western European countries had a rather rigid federal system of education which dictated the norms for the entire country. Although this had many advantages it tended to preserve the *status quo* and stifle reform. Many courses in such systems, while not lacking in rigour, failed to incorporate modern scientific content and methods rapidly enough. A second problem in these countries was the

failure of educational systems to make a provision for the cultural implications of science. In spite of the great significance of science in the modern world, many parts of Western Europe regarded the arts and the humanities as the only proper basis for education. As a result, insufficient importance was attached to science education. These two problems were further aggravated by the enormous expansion of secondary education in Western Europe. It had previously been restricted to an élite and was now being extended to all. Providing adequate science teaching materials and facilities for such increased numbers was both costly and difficult.

Between 1960 and 1964, the Directorate for Scientific Affairs of the Organization for Economic Co-operation and Development (OECD), which began as a Western European regional effort (originally OEEC), sponsored a series of conferences, publications and pilot demonstration projects in science education in various Western European countries. Science curriculum reform leaders from the United States were invited to these meetings to present their materials and ideas. As a result of these activities, a valuable series of handbooks and teacher guides was produced in some of the basic sciences and mathematics. A typical publication is: *Teaching Physics Today—Some Important Topics,* in the series entitled 'New Thinking in School Science' [26].

Because of its economic slant, OECD viewed education in general and science education in particular in terms of their roles in over-all national science policy. It produced studies in curriculum development improvement and educational development and created a Centre for Educational Research and Innovation. For a short period it focused attention on one aspect of instructional technology, namely film, and published a catalogue of 8-mm cassette-loaded science films.

Concurrent with the OECD activities was the initiation of several science curriculum improvement programmes in different member States of OECD. One of the most vigorous of these, which included projects in mathematics, biology, and physical science, was generated in the United Kingdom under the auspices of the Nuffield Foundation. These are described in the *Eighth Report of the International Clearinghouse on Science and Mathematics Curricular Developments, 1972* cited earlier [24]. The Nuffield Projects were developed to suit the pattern of science education which existed at the time in the United Kingdom with secondary-school science courses spreading out over more than one year. It is also important to mention that in the design and development of the Nuffield Projects there was a much stronger involvement of school-teachers than was the case in most of the earlier efforts in the United States. The Nuffield and OECD programmes demonstrated not only how the necessary instructional materials could be created and how teachers could be trained in their use but also had an important catalytic effect which stimulated many other reform

projects throughout Western Europe, for example in Sweden, Denmark and the Federal Republic of Germany.

For these projects there was no central source of financial support as there had been in the United States but several organizations began to give modest support and guidance. Among them were the International Council of Scientific Unions (ICSU) and Unesco. A typical activity was the International Congress on the Education of Teachers of Physics in Secondary Schools sponsored in 1970 by the International Union of Pure and Applied Physics (IUPAP) with support from Unesco and the Government of Hungary [27]. Another was the Seminar on the Teaching of Physics in Schools, held at the Royal Danish School of Educational Studies, Copenhagen, in 1969 [28]. A third example, which shows the trend toward co-ordination in science teaching which began in the 1960s was the Symposium on the Co-ordination of the Teaching of Mathematics and Physics held in Lausanne in 1967 under the auspices of *DIALECTICA, an International Review of the Philosophy of Knowledge* and GIREP, an international group devoted to the advancement of the teaching of physics. This symposium also had the support of the International Commission on Mathematics Instruction (ICMI) and of the Swiss National Commission for Unesco. Examples of international collaboration in the improvement of chemistry, biology and other sciences may be found in the clearinghouse report [24].

Science teaching reform in Eastern Europe

As we said earlier, during the 1950s and early 1960s when reform was in full swing in the West, information concerning parallel efforts in Eastern Europe was difficult to come by, due in part to the strained global political atmosphere. Even though many Eastern European countries belonged to Unesco, for example, their participation in international conferences dealing with science education, at which they could have exchanged information on the subject, was not as prominent as could have been wished. It was possible, nevertheless, for Unesco officers and occasionally individual scientists and educators to travel to Eastern Europe. From these and other sources the following very general account was put together.

The approach to curriculum reform in science in the Eastern European countries was characteristically different from that in the Western world; the main difference being that in the Eastern European countries formal provision had been made for continuous reappraisal of their science curricula and methodology by creating pedagogical institutes and academies in which research and development leading to new approaches in science teaching were constantly carried out by scientists and other scholars.

It is important to note this because the need for permanent institutions devoted to continuous reform is only now one of the goals

at which the reform movement in the West is aiming after years of intensive but sometimes sporadic reform activity. This is not meant to imply that the Eastern European countries have all along had the precise type of institution suited to Western needs—that remains to be seen—but they had institutionalized reform long ago. The following is a description of activities characteristic of reform in the Eastern European countries during the 1960s. It is probably still fairly accurate.

In Hungary, for example, the scientific committee of the Ministry of Culture and Education co-ordinated the work of all groups working on science teaching materials. The science teachers in the schools and the general public were allowed to discuss and review these proposals before they were adopted. Research into improved laboratory experiments and teaching aids was carried out by the science faculties of the universities and in the pedagogical institute of the Ministry of Culture and Education.

In Czechoslovakia, the Ministry of Education created a special advisory committee to review the science offerings of both the universities and the secondary schools. A special section of the Czechoslovak Chemical Society, for example, was established to consider the problem of chemistry teaching. Courses on recent developments in chemistry were organized for teachers, and comparable attempts were made to modernize physics and biology teaching. A centre for the modernization of mathematics and physics teaching was established in 1965 with funds from the Czechoslovak Academy of Sciences in Prague and the Ministry of Education.

Improvement and reform of science education in the Soviet Union deserves much more space than it will receive, unfortunately, in this report. It would be interesting to learn just how, from a country in which 75 per cent of the inhabitants were illiterate in 1920, the U.S.S.R. became capable of putting up the first Sputnik and demonstrating a capability in other areas of science and technology that was competitive with the best in the Western world. It suggests a massive effort in education at all levels. This is outlined in various works ([29], [30], [31] and [32]).

Some clues to the high priority given to education in the U.S.S.R. are the following: one in every three citizens of the Soviet Union attends a school or a college; education at all levels is tuition-free; a teacher earns as much as an engineer; there is an academy of sciences in each of the Union republics.

But I have found no evidence that a reform movement in science education following the patterns of that in the Western countries ever took place in the U.S.S.R. How, then, did they achieve their excellence in science and technology? Did they produce new and attractively illustrated textbooks? Did they stress the method of inquiry? Did they concentrate on new forms of instructional technology? Did they generate a massive effort to produce new materials

and approaches for science teaching? There is evidence to suggest that during the 1960s some work along each of these lines took place but not in the discontinuous and massive way it did in the West.

I think that the secret was hard work by very many people sustained over a long interval of time by gradual and possibly not very spectacular but continual improvements. In the Soviet Union all high school students take physics, chemistry, biology and mathematics for several years.

In an article entitled 'Education in the U.S.S.R. with Particular Reference to Physics' [33], J. L. Lewis pointed out that the curriculum is exactly the same for everyone in both the eight-year and eleven-year schools. He says: 'There is no specialization. Science plays an important part but in no sense is the education narrowly scientific.' Table 6 shows the number of hours per week each student spends on science and mathematics in each pre-university year.

Table 6. Number of hours per week spent by every student in the U.S.S.R. on science and mathematics in each pre-university year

	Grade								Total at end of eight years	Grade			Final total
	1	2	3	4	5	6	7	8		9	10	11	
Biology	—	—	—	2	2	2	2	3	11	2	1	—	14
Physics	—	—	—	—	—	2	2	3	7	3	4	5	19
Chemistry	—	—	—	—	—	—	2	2	4	2	3	3	12
Mathematics	6	6	6	6	6	6	6	6	48	6	6	6	66

Source: J. L. Lewis, 'Education in the U.S.S.R. with Particular Reference to Physics', *Bulletin of the Institute of Physics and the Physical Society*, July 1961, p. 189-96.

In the Russian Socialist Federal Soviet Republic of the U.S.S.R. the syllabus in science is prepared by the Academy of Pedagogical Science, final ratification coming from the Russian Ministry of Education. There are differences from one republic to another, but as the pedagogical institutes in the other republics keep in close touch with the Russian Academy of Pedagogical Science in Moscow the differences are mainly ones of detail rather than of principle.

Lewis says:

> Not only is the academy responsible for the Russian physics syllabus but also for the textbooks to be used in the republic, for the demonstration equipment, the laboratory work to be done by pupils themselves and for visual aids. In fact, they provide a course complete in itself . . . their intention is to enable the indifferent teacher to teach well.

In his conclusions, he says:

> The system of physics teaching in the U.S.S.R. is impressive and there is plenty of evidence for the success of the system. The content of the syllabus certainly shows an awareness of modern physics. It is a some-

what solid syllabus and the textbooks that accompany it lack any of the imaginative development suggested by the OEEC [now OECD] report *A Modern Approach to School Physics:* one is conscious of utilitarian objects rather than of cultural ones.

Lewis continues:

What, therefore, have we to learn from it? I would suggest there is one very big lesson. In England our teaching is geared to the good teacher. Provided a school has an inspired teacher with sufficient time to prepare his work, good physics teaching will result. In the USSR they accept that there will never be enough really good teachers (as is the case in most countries) and they have planned their system to enable the indifferent teacher to teach well. The development of aids to teaching, the thought that has been given to demonstration apparatus and to the experimental work done by the pupil, the attention to the right kind of films, all of this has meant that teachers everywhere have been given a minimum standard to enable them to achieve a certain efficiency.

My short visit to the Soviet Union in 1969 at the invitation of the Council of Ministers for Science and Technology included Moscow, Baku and Novosibirsk and permitted me to see some examples of the Soviet approach. What I saw confirmed Lewis' conclusions.

An interesting development in the Soviet Union, which I mention as an aside because it primarily concerns the gifted student only, was the establishment of experimental schools where new methods and curricula could be examined before being approved for general distribution. Four special high schools were set up for this purpose. The best known is the Fiz-Mat School, which is attached to the Novosibirsk State University. It began operating in 1962 as a two-year boarding school specializing in the teaching of the basic sciences and mathematics. After students were selected on the basis of nation-wide competitive examinations, they followed specially planned university level science courses. The class sizes were kept small and two hours per week were devoted to lectures given by scientists from the Academy of Sciences of the U.S.S.R., Siberian Department, and by professors from the Novosibirsk State University. For 7 hours each week the students engaged in problem sessions and laboratory work. Each student chose a field of specialization to which he devoted a total of 15 hours per week during his last semester. In one such session I saw a high school student develop the theory of electrostatic potential at the chalkboard at the same level used in my own college physics course for pre-medical students.

Clearly, the Fiz-Mat School is a carefully controlled university preparatory school for gifted high school students. Most of the graduates enter the university with excellent ratings. Although the pattern is very different from the reform projects of the United States and Western Europe, it does make clear that close collaboration

between working scientists, university educators, and teachers is an essential ingredient of their aspect of educational reform.

From such information as the above and from data available to Unesco I conclude that in the U.S.S.R., and probably in all of the Eastern European countries, there was not a sudden and massive surge of activity in curriculum reform and course content improvement in science as there was in the West during the 1960s but rather a continuous improvement that took place and continues to take place through the agency of the Academies of Pedagogical Sciences. I reiterate my belief, therefore, that they achieved improvement by exposing all pre-university students to courses in the basic sciences and mathematics throughout many of their high school and even pre-high school years. In this way they built up a massive reservoir of students with scientific knowledge. The very best students among them must have reached a high enough level of achievement in the science to do well subsequently in the university and at the technological institutes.

The developing countries—the work of Unesco and other agencies

While all this reform activity in science education was taking place in the industrialized countries, what was going on in the developing countries? There is no single answer that reflects the vast diversity in the level of advancement of education in the developing world.

In Africa, for example, during the 1960s, some countries were just achieving independence and were confronted by massive problems of illiteracy demanding the highest priority. But in these countries, too, some educational leaders were aware of the importance of modern science education and saw its relevance to the building up of new economic and cultural infrastructures. Work was also taking place in other regions. In Asia and Latin America, for instance, some countries in the 1960s prepared adaptations of science education materials that had been produced by science curriculum projects in the United States, a first step which subsequently led to original work. The well-known BSCS biology course developed in the United States is an example: the BSCS staff received inquiries from more than seventy countries with the result that teams were formed at various times with participating biologists from more than fifty countries.

These teams produced some forty-five national and regional adaptations of BSCS materials.

Gradually, more and more technical assistance programmes in the field of science education came into existence. The United Kingdom, for example, through its Nuffield science education projects and the Centre for Educational Development Overseas (CEDO), assisted British Commonwealth countries in Africa and Asia to develop their own science education projects. The French-speaking countries of Africa were helped through French and Belgian bilateral assistance programmes. Other countries which provided bilateral assistance in science education in those early days included the Soviet Union, Sweden and Israel.

In 1961 Unesco intensified its programmes aimed at stimulating improvements in the teaching of science at pre-university level in the developing countries. Even before the start of this concentrated effort, however, the Organization had embarked on a massive effort with support from what is now called the United Nations Development Programme, to improve primary and secondary education in the developing countries by establishing more than twenty teacher training colleges in Africa and other regions of the developing world. Many of these colleges had a science component and hence made some contribution to science education improvement. Accordingly, a Division of Science Teaching was formed at Unesco in the early sixties, and staffed by personnel who had played leading roles in science curriculum projects; and a series of pilot projects was started to promote the development of modern approaches, methods and materials for science teaching in the developing countries. These projects took place in successive biennia, beginning in 1963, in Latin America, Asia, Africa and the Arab States, in that chronological order. Expertise, initially from the United States, the United Kingdom and Australia, as well as from other European countries where reform projects had flourished, was drawn upon for part of the leadership, the other part coming from scientists and educators of the region.

The very first project of this kind took place in Brazil; it was started in 1963. It was, however, a regional project, and twenty-five professors and teachers from universities and colleges of eight different countries of Latin America came to São Paulo to spend a school year working together. They first studied modern content in physics from some of the existing physics curriculum reform projects and then participated in the writing of new materials, some of them in what was then the newest form of self-instructional programmed learning. They also invented and produced eleven short silent films for a cartridge loaded 8-mm motion picture prejector, one long sound film and eight different boxed kits containing inexpensive laboratory materials, all for the teaching of a selected subject—the physics of light. They likewise produced a teacher's manual and the script of several television programmes which were first tried out on Brazilian television [34], [35].

At the end of the year, a four-week seminar was held to which senior leaders in physics education from the region were invited. They tested the new materials and planned ways to introduce them into the educational systems of their own countries.

An essential aspect of the project was that practising teachers had become involved in the creation of the new materials. A strong emphasis was placed on 'hands-on' experiments which could be done by the students themselves with relatively inexpensive equipment. What evolved is now called a 'teaching package' or a 'module', all of whose parts had been developed in a co-ordinated manner to supplement one another in the teaching-learning process. There were, for example, some questions in the programmed learning sequence which could not be answered by the student until he had performed an experiment using the kits. The films all showed experiments, some of which might have been difficult for the student or the teacher to do on his own. The materials were produced in Spanish and Portuguese although some of the early writing took place in English because the outside experts who had come to help as consultants in specialized areas such as programmed learning and film production came from English-speaking countries.

It would have been better, of course, to use only experts who spoke Spanish or Portuguese but these were hard to find and possibly non-existent in those days. The foreign experts who stayed on for the entire project did learn Portuguese. The participants each took home five complete sets of the teaching materials they had helped produce, which in some cases listed them as co-authors. In retrospective we know that some of these materials were used over and over again during special summer school retraining courses for teachers in their home countries until they were practically worn out or in some cases replaced by new and improved models which were designed and produced in the individual countries.

In subsequent biennia, other Unesco pilot projects on new methods and techniques in teaching took place: in Bangkok, chemistry for Asia; in Cape Coast, biology for Africa; and in several different Arab countries, mathematics for the Arab world. The pattern of the different projects kept changing to accommodate itself partly to the different demands of the basic sciences and partly to the differences in the educational needs and languages of the regions. The directors of each new project naturally tried to rectify errors made in previous pilot projects and to benefit in all possible ways from the experiences of the past.

An example of an improvement in these pilot projects that suggested itself as time went on was the need for advance planning for the dissemination of the results of a given project throughout the region. For this purpose national study groups were formed in the participating countries long before the pilot project was launched in that region. These groups received materials in their subject areas

produced in earlier curriculum reform projects. This laid the groundwork for the creative task which the regional pilot project participants would eventually have to do. Some of the members of these same groups stayed home during the creative phase of the project to test the materials being produced and generate a 'feedback' signal to the project before the final version was settled upon. Later, they were instrumental in disseminating the results of the project in the region.

Some of the later projects had a long lead time for preparation and as many as twenty study groups were set up in advance throughout the region.

In Africa, the needs of both English- and French-speaking countries were met by separate but related projects. In the Arab States, where the mathematics project took place, it was decided not to gather all the participants in one country for the whole school year but to have different parts of the projects done in different countries although with co-ordinated central planning and periodic short meetings of the leaders of the different subgroups to unify the final presentation. The mathematics project, unlike the others, did not produce audio and visual aids or programmed learning materials, perhaps reflecting the different tastes and inclinations of its leaders and possibly also their conclusion that the subject of mathematics did not lend itself to these approaches.

If they did nothing else—and there is reason to believe that they did much more—the pilot projects demonstrated that new approaches and materials could be generated within the separate regions of the developing world by local scientists and educators with the support of international teams of experts.

Space permits discussion of only one other aspect of the work of Unesco in promoting change in science education. This came about through its publications programme. To make information about modern approaches known to teachers and scientists, especially in developing countries with adequate access to the literature of the rest of the world on these matters, Unesco produced a variety of handbooks and sourcebooks on science education. The 1960s saw the introduction of a new series entitled 'New Trends in the Teaching of the Basic Sciences'. The purpose of this series, which included publications in physics, chemistry, biology, mathematics and more recently on integrated science was to help teachers keep abreast of modern developments in the teaching of their respective subjects.

In retrospect, what did we learn from the projects? What went wrong? What worked well?

One of the most important things we learned from the movement for reform in education that began in the 1950s was that successful innovation in this area is dependent upon the same kinds of factors as is innovation in general. That is, there has to be recognition of a need; entrepreneurs must arise who will invent and promote in spite of what seem like insurmountable obstacles; and financial support must be found to get projects started and usually tied to administrative support from some official quarter like the ministry of education which will then push for a widespread implementation of the reforms. The formula varies in its details from place to place and from country to country but it is usually a variation on this main theme.

The next thing to observe is that in 1974 the movement 'is alive and well and living' in more than thirty countries with a total of about 300 projects—roughly half of them in the United States. These figures are based upon the *Eighth Report of the International Clearinghouse on Science and Mathematics Curricular Developments, 1972* [24] which, unfortunately, has practically no information concerning the activities in the Soviet Union and other Eastern European countries and nothing at all about China.

While there is no longer the massive support for individual large-scale projects which characterized the start of the movement in the industrialized countries, the sources of support have multiplied nationally, regionally and internationally. Mechanisms have been invented for exchange of information and materials between one project and another on an international scale. Thus, we observe that in the U.S.S.R. a translation of the PSSC textbook was made although not for official use as a textbook but as background material for the training of teachers. Information has also flowed in the opposite direction. The School Mathematics Study Group has, for example, made available to students and teachers in the United States problem books based upon the rich Hungarian experience in the teaching of mathematics.

The following are some observations responding to the questions: What did we learn from the projects? What went wrong? What went well?

Involvement of scientists was vital

Scientists brought two important elements to the early projects—first, a knowledge of modern contents in their field and secondly an element

of prestige which enhanced acceptance of the need for reform and the possibility of obtaining financial support. In some cases the scientists were forced to enter areas in which they lacked experience. They were not experienced in the day-by-day classroom teaching at the high school and elementary levels and in some cases produced materials which were too difficult for both teachers and students to handle. They did not know enough about the learning process nor about the effectiveness of the media but they were entrepreneurs in the true sense of the word. They were enthusiasts, driven by a faith in the ultimate outcome of their innovative activities. They have been vindicated, for the errors which they made generated the feed-back which eventually began to put reform back on course.

Several different approaches to innovation are probably better than one

If we accept the thesis that there is no best way to reform but that there may be several different acceptable ways, then the financial support should not go exclusively to a single project in a given field. Where massive support was given to a single project a feeling tended to grow among its proponents that 'the best' programme had been created and that what was then needed was simply large-scale implementation, including translation into other languages for use in other countries. Eventually, of course, other innovators came along, observed the new needs for change and obtained the financial support for alternate approaches.

Adaptation is better than adoption

It was especially true in developing countries but also in others that a straight adoption of a programme was either difficult, undesirable or both. In some fields, such as physics, one might argue that the concepts involved are universal and need no adaptation from country to country. There is an element of truth in this, of course. There is only one universal law of gravitation and the propagation of waves in elastic media obeys the same formulas in Timbuktu as it does in London. Nevertheless, the language and the examples used in the textbooks that expound this law have to be understandable and seem meaningful in the social and cultural milieu for which they were written.

There is also a psychological factor involved. If a group of teachers in Latin America, say, is given a textbook written for the United States and told that this represents the best thinking on the subject on the part of a group of high level scientists and educators, the simplest action for them to take is to translate the book into

Spanish and use it but this may not be the best way to infuse them with a desire to use it. An alternative is to let them study it, adapt it and hence modify it to fit the educational needs of their own country as they see them and end up with an adaptation that bears their names as co-authors. Pride of involvement generates a desire to actually use the new materials that is not present in the case of a straight translation.

In other subjects, especially in biology, for example, where the flora and fauna of one region may differ greatly from those of the region in which the original book was written, it is imperative to adapt rather than adopt.

Involvement of teachers in the creative or adaptation phase is important

The eventual success or failure of the materials produced by a project depends on whether in the actual classroom situation the teachers are willing and able to use the new materials. All the major reform projects saw the importance of this and modified their method of operating to include teacher training. The teacher has to feel at home with the new materials. One way to achieve this, if they were not involved in their development, is to give special courses to the teachers so that they feel at home with the new approaches and materials. The course will never succeed unless the teachers use the materials in the right way. Teacher training is therefore of vital importance. But I am also pleading here for a more direct involvement by at least some of the teachers in the creative process that takes place when the new materials are first being dreamed up. In the Unesco Physics Pilot Project, for example, teachers were part of the innovative team. The books produced bore their names as co-authors. They were also involved in the discussions on objectives that precede the writing of programmed-learning materials, in the production of story boards for films and in the invention and development of the inexpensive home kits. In the process two things happened; their knowledge of the subject matter was sharpened up in discussions with their peers and with the experts who came to lead the projects and, secondly, their enthusiasm for the actual classroom use of these materials was built up.

Perhaps in future teacher training courses in established institutions, more opportunities may be opened up to use the teachers-in-training in this creative way.

Emphasis on 'hands-on' experimentation in the laboratory and in the field was well placed

It is my opinion that the weakest part of science education in developing countries is still in the area of experimentation by the student. There has been a tradition of 'chalk-and-talk' exposition of subject matter which replaces actual experimentation by the student. It is true that economics has been the limiting factor in many cases. This was often aggravated by an almost complete dependence upon very well made and often highly polished equipment from the industrialized countries. Such equipment looks glamorous and works with apparent ease to achieve the numerical results which are often the desired outcome of the experiment. It is also easy for the teacher to set up but tends to stifle the real spirit of investigation which in some cases proceeds even better with crude and inexpensive equipment.

Many efforts have been made, initially by the projects in developing countries, to produce low-cost equipment which can be handled by the student himself. In the industrialized countries, the initial creations of the PSSC, for example, were taken up by commercial manufacturers for mass production. To help launch the project on a large scale this was a boon but it turned out that the cost of this equipment, even when manufactured locally in developing countries, was still too high to reach all the schools.

I believe, therefore, that this is an area where a new level of innovation is required. Even the cheapest equipment available now is in some cases higher in cost than it should be for massive dissemination in most developing countries.

The basic idea of experimentation by the individual student is correct. It has not yet reached the very poor around the world.

Production of software for the media should be given greater weight than the purchase of hardware

The promise of films, television, audio and visual aids and self-instructional devices—the 'things of learning'—has not yet been fulfilled anywhere in the world. It is true that such devices have the potential, at least in part, of solving the problems stemming from not having enough teachers sufficiently well prepared to teach science and mathematics in the imaginative and creative ways which we associate with the reform projects. There has been a tendency for school systems to buy the hardware that might make the dreams of instructional technology come true. It is often the easy way to spend money once it becomes available. You spend it on the gadgets of learning, which may have been teaching machines in one era or closed-circuit television in another. The weakest link in these systems is usually the low quality of the software. This is not universally true,

of course. Some extraordinarily good films have been produced. A much smaller number of good programmed-learning sequences have been written.

The problem is that it takes money to produce good software and money has always been in short supply. In fact, in the industrialized countries we have often left it to private industry to generate the films, filmstrips, tapes, and programmed-learning sequences, that is, the whole teaching package or 'module' needed for the type of teaching that utilizes modern media. The results, with some notable exceptions, have not been outstanding. One reason may be that the materials were not validated with trial students.

One of the things that has gone wrong, perhaps, has been the tendency to begin with sophisticated hardware. In the realm of visual aids, for example, it is actually much cheaper to start with transparencies for the overhead projector made by the teacher himself than to go directly to the production of motion picture films or even to the use of closed-circuit television. The lessons that have to be learned by teachers for communicating through sophisticated media can begin with the use of the overhead projector and the cassette tape recorder.

In the early days of radio, thousands of amateurs built crystal radio sets and later progressed to circuits with one or more vacuum tubes. In the process many people learned the possibilities of radio communication and some of them—those with the necessary scientific curiosity or technical skills—became radio engineers and technicians. Perhaps we need a massive movement to promote the use of the least expensive audio and visual media. The visual part could be overhead transparencies for the overhead projector or 35-mm slides (which, incidentally, have remarkable colour fidelity and resolving power) and the sound could be recorded on one of the many available and relatively inexpensive magnetic tape recorders. From among the thousands of teachers who could be involved in such a movement might come the future audio and visual software specialists of the future. My point is simple; do not begin by dreaming about blanketing a region using television transmitters in orbiting satellites without putting in at least as much effort on the serious problem of generating viable software for these future teaching systems.

We still know too little about the process of learning

Most efforts at improving the teaching-learning situation have been made on an impromptu or improvised basis without the benefit of modern knowledge about how learning actually takes place. In time those responsible for new project began to listen more carefully to what the psychologists had to say. In some cases they listened perhaps too attentively to the latter's ideas about objectives, and how to write them in behavioural terms and how to measure the outcome of the

learning process, but it seems to me that we are still in the dark about what really takes place in the learning process and about the factors that affect it. It was right to consult our colleagues in psychology. What went wrong is that we still have no good basic theory of learning on which to build our instructional sequences and devices in a rational way.

We learned that international collaboration was possible

There is ample proof that the reform movement 'caught fire' world-wide. National, regional and international agencies have aided and abetted the process. But, as we said earlier, there are regions of the world that have not participated sufficiently in this give-and-take even though they do belong to the international organizations that sponsor reform activities.

The need for integration is greater than ever

The need for an interdisciplinary approach was recognized as early as 1956 by the Physical Science Study Committee but the concept of integration in science teaching had to wait until the second-generation projects like PPC and ESCS. For the first decade the projects remained for the most part single-discipline oriented. Perhaps one of the main thrusts in the near future will be co-ordination and integration in the teaching of the sciences and greater concern for the integration of science into the whole curriculum.

Some of the early projects did not adequately reach their target populations

Some of the courses that were aimed at 'Everyman' that is, at the average high school student, turned out to be excellent for the gifted students and too difficult for the rest and even for some of their teachers. Projects in successive generations have begun to correct this.

Evaluation of the projects has been difficult

The whole idea that the objectives of a project should be stated in advance in measurable behavioural terms is relatively new. If such an approach had been adopted before the earliest projects got started, however, they might never have got off the ground.

This idea of evaluation is, however, an important one. It is linked to the concept of 'measure of effectiveness' used in operations

research. These ideas have crept into science education reform under the broader cover of the 'systems approach to education' in which the educational process is considered in much the same way as a technological one with inputs and outputs. I shall have more to say about this in another section.

Suffice it to say that evaluation both of projects and of the students who were subjected to the courses has always been recognized as important and given some consideration but that a new break-through is needed.

We learned that reform has to be a continuous process

The discontinuity produced by the infusion of massive support to the early projects produced tremendous animation and excitement but when that died down we were compelled to recognize that all that had occurred had been just a beginning and that improvement had to be a continuous effort. The idea that permanent institutions—science teaching centres, for example—might be funded to permit continuous innovation and change began to take hold and international funding agencies gave support to the formation of several such centres in several countries. This is an area in which, perhaps, the countries of the Western world might stand to gain from the experiences of the Eastern European countries where, as we have noted, continuous reform has for a long time been programmed through their academies of pedagogical science. But just as conceivable is the idea that the Eastern European countries have something to gain from the tremendous variety of efforts that have taken place in the Western world where the multiplicity of educational systems and sources of support have generated approaches which may have a relevance in Eastern Europe. Clearly, better international communication is needed.

The method of inquiry is not enough

It was natural that the mode of action which motivates scientists—the search for knowledge and understanding—should have played such an important role in the early projects that benefited from their inputs and leadership. In the past decade, however, during which technological triumphs on an unprecedented scale were taking place—in space, for example—a disenchantment with science was also being generated by events in the world. These included the atomic bomb, Viet-Nam, and a new concern for the environment. Science and technology changed almost overnight from hero to anti-hero. Students ceased to want to go into science, which they thought had let them down in the solution of basic world problems. The relevance of this to science education is, I think, that very few of our students are

going to become pure scientists. Serious cutbacks in research have created unemployment. Curiosity, a driving force behind scientists, is necessary but not sufficient for the solution of the real problems of the world. In their day-by-day problems most people might gain more from the use of the design mode of action associated with engineers and technologists than from the use of the investigative mode of action that characterizes the pure scientist. Learning how to map out a course of action that will lead to success in the solution of real problems may be something that will have to infuse the teaching of science in the future.

5

Some promising new trends in science education

We are now ready to look at the future of innovation in science education and to ask what new paths should be tried. In the next chapter we will look at specific examples of new activities for priority action but before doing so let us first describe in very general terms four new trends in science education.

The trend towards teaching science in relevant and socially responsible ways

The need for relevance and responsibility

We will begin by clarifying how the words relevant and responsible are used here and then proceed to show how they are currently considered in connexion with science education.

Although we have described the search for knowledge for its own sake as a worthy end in itself, scientists—especially those of a philosophical bent—have also sought elsewhere to determine the relevance of science to human needs and aspirations.

Some of the early scientists sought this relevance in a divine order of things. For Newton, for example, the relevance of astronomy must have been related to the divine origin of the solar system for he says in his *Principia* [36]:

This most beautiful system of sun, planets, and comets could only proceed from the counsel and dominion of an intelligent and powerful Being.

In recent times, however, there has been a shift, among some philosophers and scientists, from the concept of a divine order to that of a natural order and a corresponding shift from deism to humanism. It is said of the contemporary philosopher Karl Popper, for example, that his philosophy deals with two major problems: first, how do we increase our scientific understanding of the world? Second, how can we improve our social institutions? A concern for man has crept in.

This humanistic trend was also expressed by Josiah Royce in his Introduction to Poincaré's *Foundations of Science*: 'Man is not merely made for science, but science is made for man.' Henry Margenau, who quoted the above, also says: [37]:

> It is not enough for us to fear or admire science, the greatest challenge of our day is to *humanize* science, that is, to speed up the evolution that will set it into an organic relation with philosophy, with culture and with life.

This, it seems to me, is a good way of describing the objective of a science education that is relevant the human needs and aspirations.

The focus of the other term—responsibility—has also shifted from a deistic to a humanistic interpretation. It now often means a sense of social responsibility born of a concern for other human beings.

To understand why relevance and responsibility enter our consideration of modern science education one must see them in the context of the economic and political forces that were tearing society apart in the 1960s.

Spearheaded by student revolts in many countries, a search for relevance on a broad front was begun and a great deal of experimentation took place in search of new life styles. It was also during the sixties that the ecologists and environmentalists, some of whom had been at work for decades, finally began to make us all aware that the earth is finite and cannot survive for long as a habitat with the present wanton waste of energy and natural resources and that the human race cannot withstand the onslaughts of pollution of earth, air and water.

In this setting it was only natural that some scientists, with the shadow of the nuclear bomb still over them, should feel a share of responsibility and begin to seek new ways in which science and technology could better serve mankind. It was becoming clear that responsibility is a two-way street in which scientists have a responsibility toward society and society has the reciprocal responsibility of learning enough about science to make reasonable decisions on how to use the evolving technology. Some individuals, scientists included, felt that their responsibility lay in finding ways to make science and technology education itself relevant and responsible.

Among them, innovators and entrepreneurs began to arise who sensed the need for new courses and materials to give science education a relevant focus. The relevance of science to the human good is easier

to exemplify in the biological sciences than in the physical sciences. Because biology is the science of life, for example, it lends itself naturally to a relevant approach although, as Hurd pointed out, this has not been adequately done. In physics, on the other hand, it is harder to find topics that seem relevant, except for energy whose importance to our way of life is finally being acknowledged. Within physics, a subject like the theory of relativity seems abstruse and of little relevance except in so far as it stresses the intimate relation between mass and energy which springs from relativity and is basic to an understanding of both nuclear fission and fusion—potentially two of our most important sources of energy for the future.

I need not pursue this idea with examples from chemistry, or the sciences of earth and space and mathematics.

The best proof, perhaps, that the need to teach science in relevant and responsible ways has been recognized is that many different kinds of responses have begun to appear not only in the separate disciplines but in interdisciplinary efforts as well. The following is a sampling of these responses in the form of publications, courses, conferences, symposia and other activities.

Responses to the need for relevance in science education

Publications

There are now hundreds of books dealing with the problems of science and society. Some of them are very general and do not touch upon science education except by implication. Others address themselves specifically to the task of changing the course of science education to make it more responsive to the needs of society.

In the general category I would include books like: *Only One Earth* [38]; *The Closing Circle* [39]; *Energy and the Future* [40]; *Resources and Man* [41]; *The State of Siege* [11]; *Population, Resources, Environment* [42]; *The Environmental Handbook* [43]; *Population, Evolution and Birth Control* [44]; *The Step to Man* [45]; and *Learning to Be* [46].

There exists, fortunately, a bibliography containing over 3,000 entries which exemplifies the concern of the science education community for relevance and responsibility in science teaching [47]. It is the fifth edition (1974) of the annotated bibliography entitled *Science and Society*, prepared by Felicia West for the Commission on Science Education of the American Association for the Advancement of Science. The entries are in the broad areas of: science, technology and society; resources and the environment; education; health; conflict and population. Other key subjects like pollution, poverty, peace, energy, ecology and food fall naturally into place along with about ninety other topics. Some of the books mentioned earlier will, of

course, be found in the bibliography. Since it was designed for use in American schools, it is not an international source of information. It is, nevertheless, very useful and indicative of this new concern of scientists for social issues.

Under education there are about 300 references with headings such as curriculum trends, environmental education, higher education, methods, teacher education, technology and many others. Although many of the publications listed are books, others are pamphlets and some are articles in journals and magazines. Two of the most useful magazines are, of course, *Science and Public Affairs* (formerly *The Bulletin of the Atomic Scientists*) and Unesco's *Impact of Science on Society.*

Textbooks in the sciences are a special category of publication and are not covered in the bibliography but during the past few years some authors have attempted to write physics, chemistry and biology textbooks with a social slant. The best place, probably, to find the titles of these would be the book sections of the journals that deal with the teaching of these scientific disciplines.

Since physics is my field of scientific interest I went through the book sections of the *American Journal of Physics* for the past two years to see if the titles suggested a societal concern. Of the textbooks reviewed, *Physics for Society* by W. B. Philipps (40, p. 787)[1] was the only one whose title clearly indicated societal concern but many of the recent books have either a chapter devoted to this issue or make mention of it under special topics such as nuclear fission and fusion. (A book not reviewed in the journal is *Physics and Man* by Tor Ragnar Gerholm, Bedminster Press, 1967.)

The books received for review also indicate that there is interest on the part of publishers in having items of societal concern reviewed in the physics education journals. Among books received one finds such titles as: *The Shape of Likelihood; Relevance and the University* (40, p. 216); *Patient Earth* (40, p. 786); *The Extension of Man* (40, p. 1356); *Man and Atom* (40, p. 1353); *Ecology, Pollution, Environment* (40, p. 1560); *Technology and Man* (40, p. 1561); *History in the Teaching of Physics* (40, p. 1721); *Man and the Computer* (41, p. 307); *Science and Controversy* (41, p. 452); *Science and Human Destiny* (41, p. 1125); *Impact of Basic Research on Technology* (41, p. 1383); *Problems of our Physical Environment: Transportation, Pollution* (41, p. 1383); *Statistics and Society* (41, p. 1383); *Technology, Man and the Environment* (41, p. 1383).

Some of the articles in the journal also reflect this new concern. A case in point is: 'Toward Wider Public Understanding of Science' by Arnold Arons (41, p. 769). Some of them deal specifically with the development of new courses. One is 'A Humanistic Approach to

1. The numbers in parentheses here and below refer to the volume of the *American Journal of Physics* and to the page.

Science' by John L. Roeder (40, p. 1615) and another 'War, Peace, Science, and Technology in the Atomic Age—A Physics Course for the General Student' by R. A. Uritan (40, p. 1324).

I am certain that a perusal of the book sections of the various journals devoted to the other sciences would reveal a similar trend world-wide.

Courses

Besides project physics and the earth science curriculum study courses already mentioned, several new courses with a societal slant are listed in the *Eighth Report of the International Clearinghouse on Science and Mathematics Curricular Developments, 1972* [24]. Under 'Great Britain' for example, we find the following projects: science, technology and society (p. 266) and, of course, the whole programme of the Open University (p. 216). In the Science Foundation Course of the Open University there is an entire unit entitled 'Science and Society', and the Technology Foundation Course stresses societal problems under the heading of 'The Man-made World'.

In Israel there are projects entitled 'Agriculture as an Environmental Science' (p. 352) and 'A Socially Oriented Approach through Carbon Compound Chemistry for Non-science Majors at the Secondary Level' (p. 386).

In Colombia there is a biology course entitled 'El Hombre y su Ambiente' based upon the Green version of the BSCS course (p. 401).

The Ontario (Canada) Department of Education produced, in 1972, guidelines for the Intermediate and Senior Divisions dealing with the interactions of man, science and technology, both past and present. This publication *Man, Science and Technology* is intended to give interested students some insight into the influence of science and technology on human affairs. It contains an extensive bibliography. (This publication has the identification number 1017.)

In the United States there are projects such as 'Humanistic Approach to Natural Science' (p. 609); 'Science, Nature and the Survival of Man' (p. 811); and no less than fifteen projects dealing with the environment.

Conferences, symposia and other organizational activities

A third form of response to the need for relevant and responsible science education has been the organization of conferences and symposia in which this topic has been discussed. My objective in citing these few examples is to give the reader for whom this is a new topic a feeling for what is going on and enough information to enable him to obtain some documentation on the subject.

A recent conference whose title conveys the idea of science

education in a societal context was the Commonwealth conference held at the University of the West Indies in Jamaica in 1973 on 'The Social Significance in Science and Mathematics Teaching'. A copy of its report may be obtained from the Administration Officer, Commonwealth Foundation, Marlborough House, Pall Mall, London S.W.1. (United Kingdom). It contains many ideas and several recommendations worthy of study both in and out of the Commonwealth.

Several international conferences have recently considered the topic of science education in a societal context as part of a broader agendum. The International Council of Scientific Unions (ICSU), collaboration with Unesco and the University of Maryland, held a conference on 'Education of Teachers for Integrated Science' with the subtitle 'Teaching Science for Today's Society'. One of the plenary sessions was devoted to 'The Social Responsibility of Science and the Reciprocal Responsibility of Society'. Its report is obtainable from D. G. Chisman, British Council, Tavistock House South, Tavistock Square, London W.C.1 (United Kingdom).

The Committee on the Teaching of Science of ICSU was responsible for planning this conference and will probably continue collaborating with Unesco and other organizations on future projects of this kind. Tentative plans are also under consideration for collaboration with two other ICSU committees: COSTED (Committee on Science and Technology in Developing Countries) and SCOPE (Scientific Committee on Problems of the Environment). The focus of these activities will probably be science education, natural resources and the environment. Information on these may be obtained from ICSU headquarters at: 51 Boulevard Montmorency, 75016 Paris (France).

An example of a regional conference was Science and Man in the Americas, held in Mexico City in 1973. It devoted several days to a central theme entitled 'The Importance of Education in Development'. The societal theme ran implicitly throughout many of the presentations and explicitly in a paper entitled 'Socially Productive Education at High School Level'. It was co-sponsored by the American Association for the Advancement of Science (AAAS) of the United States and the Consejo Nacional de Ciencia y Tecnologia of Mexico. Its report is available from the American Association for the Advancement of Science, 1776 Massachusetts Avenue, Washington, DC 20036 (United States).

The fifth Rehovot Conference on Science and Education in Developing States was held in Rehovot (Israel) [25]. Among the delegations were twenty cabinet ministers and two deputy cabinet ministers, forty-five administrators in the field of education and forty-eight scientists. They considered, among other things, the aims of science and education. One paper dealt specifically with the question 'Is Humanistic Science Appropriate for a Developing Country?'

A small conference was organized by Scientists and Engineers for Social and Political Action (SESPA) and held in Berkeley, California, in 1973. Considerable attention was given to the social and political issues which should be taught as part of all science courses at different levels. The September 1972 issue of their journal entitled *Science for the People* was devoted to science teaching and contains a good exposé of a Marxist point of view on this subject.

The Society for Social Responsibility in Science held a conference entitled 'Food for People' in which the role of science was explicitly discussed and that of a responsible science education implicitly. In 1971, the society held an International Pollution Control Conference in which one theme was 'Information and Education on the Environment'.

Unesco has, of course, organized many international and regional conferences on science education in which the societal problems, especially of the developing countries, have been considered. The recent ones most closely linked with science and society have been those on integrated science which will be discussed in another section.

At the Roskilde University in Denmark a project dealing with an interdisciplinary societal relevance approach to the entire curriculum has been in progress for several years.

The trend towards a systems approach to education

Origins of the systems approach

The term 'systems approach to education' implies something more than looking at education in a systematic way. Before we give some examples of precisely what it means, however, it would not be wrong to think of it, tentatively, simply as a systematic approach.

The terminology of systems approach arose, however, out of its use in large-scale systems other than in education. Usage varies and some authors use the singular form 'system approach' but there good precedent for using the plural form 'systems' and I will adhere to it except where it seems clearer to use the singular as in 'system analysis' and 'system design'.

The trend towards a systems approach in education in general and science education in particular is not yet as visible nor as strong as the trend towards the teaching of science in relevant and responsible ways; no international conference or symposium on the subject, for example, has yet been held, but I believe it is an important trend and worthy of encouragement.

The concept of a systems approach has several antecedents. One of these is operations research—sometimes called operational research—the name originally given to the application of scientific methods and knowledge to the solution of certain very complex war-related problems involving large systems containing many men and machines. The application of operations research is credited with turning the tide of submarine sinkings in favour of the Allies in the Second World War. The defence of the United States fleet against air attack is another example of the type of problem on which it was used.

An important idea in operations research is that one must specify, before proceding to analysis of the problem, a quantitative measure of effectiveness for the operation by means of which one can gauge the success of proposed solutions. Modelling, using physical or mathematical models amenable to computer simulation, was often resorted to so that trial runs of the model could yield a measure of the effectiveness of the solution. In the case of the submarine problem mentioned earlier, for example, the total number of submarine sinkings could have been a measure of effectiveness of the operation.

By the end of the Second World War the concepts of operations research had also begun to be applied to large-scale man and machine systems dealing with peacetime activities such as the management of large business and industrial firms.

Another related development was the invention of programmed instruction (it is now usually referred to as programmed learning to put the emphasis on the output rather than on the instructional procedure). This evolved, in part, from the self-instructional tool called the teaching machine which has since almost vanished from the scene. An important lesson learned from attempts to write sequences for teaching machines or programmed instruction was that it is necessary to state the objectives for the learner in operational terms. This is obviously related to the idea of measure of effectiveness in operations research.

The most useful aspect of all the projects that involved people in writing such sequences was, probably, the mental exercise which the authors had to go through in specifying what the student should be able to do that he could not do before taking the course. They had to specify the desired behavioural changes—hence the term behavioural objectives.

The key idea, then, is that it is important to specify objectives in such a way that the success of the programme can be evaluated or assessed by comparing quantitatively the results with the objectives.

To determine success or failure, therefore, you check the output in terms of your specified objectives.

Some of these ideas when applied to management and industry led to techniques such as critical path analysis and Program Evaluation Review Technique (PERT). In the latter, the concept of feedback is implicit since the object of the review procedure is to modify the programme on the basis of information generated in the development.

The simplest illustration of feedback is, perhaps, one which we mentioned earlier—the control of the temperature of a room by means of a thermostat. But if you grew up in the early days of radio you may remember another example. Certain radio sets squealed in the tuning process. This was probably produced by a so-called regenerative circuit because some of the output signal was fed back into the input to produce amplification. If the feedback signal was too strong the circuit would oscillate. The build-up or regeneration of the signal was caused by positive feedback. This was my first encounter with the term. Its implication was indelibly impressed on my mind. It is also possible to produce negative feedback—that is, a signal fed back in order to reduce rather than increase the output signal. Both kinds of feedback play important roles in the control of systems.

Cybernetics, a field of activity associated with the name of Norbert Wiener, has come to mean the science of control and communication. Obviously many of the things we have been talking about belong in the realm of cybernetics and some authors like to use this word in connexion with systems analysis, but I shall seldom use it because to some non-technically oriented readers it may have an inhuman connotation. Whatever words we use, however, we will be dealing with systems involving human beings and machines, both subject to rational control.

The general concept of a system

We shall soon be discussing educational systems but first we must see what characterizes systems in general. We speak, for example, of a solar system, the digestive system, political and social systems and the transport system. The huge corporations and governmental organizations are called socio-economic systems because they combine technological systems with human management.

Systems often appear in a hierarchy, that is, in a structure in which the large systems encompass the smaller systems. The human body is a system and the central nervous system is a subsystem within it. The abstract concept of systems has led to what is called general systems theory which attempts to provide an integrated framework for the analysis and understanding of systems—all kinds of systems.

A set of interconnected elements which have been identified as

worthy of isolation for consideration may be a system. A collection of coins in a box may be worthy of consideration but because the coins are not interconnected and are not doing anything they are not a good example of a system.

The planets orbiting round the sun constitute a system. They are doing something and they are held together by gravity so they are interconnected; but man does not have control over the solar system and we will be interested more in systems in which man does exercise control because the educational system is of that kind.

The essential point of a system is that the elements perform specified functions so that the system as a whole can perform its prescribed function.

In dealing with systems we are usually more interested in the over-all behaviour of the system than in the behaviour of its individual components. The telephone communications network, for example, is a system. When we use it to place a long-distance call the message may be transmitted by cable or by a microwave relay. We do not usually care by what means the message was carried. We do care about the effectiveness of the whole system.

Here, then, is what characterizes a system:

1. It is an assembly of parts or components connected together in an organized way.
2. The particular assembly has been identified by a human being as of special interest.
3. In general, the parts are affected by being in the system and they are changed if they leave it.
4. Our assembly of parts does something. (In some special cases, its behaviour may, however, consist of not doing something when the outside world changes.)

Since we are going to think about educational systems you might, as an exercise, re-read the four points above and try to imagine how they apply to an educational system. (For a good discussion of learning systems see Berman's article on learning media [65].)[1]

The above definition and many of the ideas in this chapter were derived from the Open University textbook for the Technology Foundation Course entitled 'Systems' to which the reader is referred. It contains classifications of systems and other interesting details and a suggestion that general systems theory has evolved some 'laws' which apply to all systems but which we cannot take the time to consider. Throughout the book the authors stress the importance of the intuitive

1. Berman says: 'The components of a learning system, or the subsystem elements, all have the specified objective of working together in order that an individual who interacts with the system eventuates in learning.' He also discusses: media classification schemes, media subsystems, media selection criteria, basic learning systems and practical utilization of learning media.

element in the systems approach. They also distinguish between system design and system analysis. Here, in summary form, are some of the things they say.

System design

If you are starting from scratch to design a new system you must begin by setting out the objectives of the exercise. You will then have to draw up a tentative boundary to your system. Next you must think of possible subsystems and their interrelationships. The feasibility of the subsystems must be established and, when snags emerge, the previous steps will have to be repeated or iterated until feasible subsystems do appear. Now the interactions between subsystems must be modelled. This may be done mathematically in some cases but usually a model with real hardware like a wind tunnel or a computer may be needed. Let the model run and note what happens. The real system then has to be realized or constructed and tested.

System analysis

If you are primarily concerned with system analysis you will probably start with a problem. The existing system is failing to achieve its objectives. (We see at once that most existing educational systems fall into this category and demand system analysis. On the other hand, in a developing country where the educational system may have to be generated from scratch, the concept of system design may be applicable.) The system analysis will be complete when you have discovered enough about the system to be able to predict its behaviour. With a system as complex as an educational system even moderate success at prediction would be a great step forward.

How did the systems approach enter education

We can answer this question by noting the titles of some publications on the subject and the professional interests of their authors.

Alex M. Mood of the University of California at Los Angeles in his address as retiring President of the Operations Research Society of America said [48]:

> The text of my little sermon is: Diversify. I believe our talents are too much monopolized by the defense business. . . . My purpose in this talk will be to show that there are important areas in which we are making little or no contribution and in which operations analysis has the potential to make salient contributions.

The areas he names are education, health, welfare, agriculture, and urban affairs.

Under education he discusses several problems in which operations analysis (which we can read as system analysis) can be utilized. These include the problem of the worth of an education, the criteria for changing curricula, vocational training and the economics of education.

He singles out programmed learning, of which he says:

> There may be something of a revolution coming to education because of the so-called teaching machine developments. The machine aspect may not be so important but surely the programmed-learning idea *is*. . . .

Another example appears in a paper entitled 'Educational Planning in Developing Countries—A Possible Role for Operations Research' by R. M. Durstine and Russell G. Davis of Harvard University [49]. They say:

> Education as a whole has been recognized as a field for the application of operations research and its allied methods for some time, with a recent growing interest under the title systems analysis. This interest seems to have enough momentum that operations research in education is well on the way to a clear definition and development.

The aim is to encourage the exploitation of these techniques particularly as regards planning in centralized national systems, with special reference to developing countries. The authors say:

> The possible activities are those of operations research at the most fundamental level. Questions of problem definition, models, and measures of effectiveness are at the forefront. The need is for simple and direct solutions to practical problems. The profitable use of highly developed and sophitisticated techniques is far off. But if the problems are simple, they are deceptively so. They involve almost every subtlety that operations research people tell one another it is important to consider.

Besides the systems analysts, a small group of educators have been instrumental in using the systems approach to education. B. Spector, T. K. Steele and L. R. Eilbert have authored a trio of papers [50] under the title: 'A System Approach to Technical Education'. They discuss systems analysis applied to technical education, some operational considerations and the role of measurement and evaluation in their project.

A third type of individual involved in this activity is the professional analyst working in industry. L. F. Carter of the Systems Development Corporation of Santa Monica, for example, delivered an address entitled: *The Systems Approach to Education—The Mystique and the Reality* [51]. It contains a good explanation of the systems approach and several examples of projects in which it was used. One of these was a training programme for the air defence

system and another was an introduction to reading for Mexican-American children. It concludes with an illuminating evaluation of systems analysis applied to the problems of education. Carter says:

In summary, system analysis [he uses the singular form] is a point of view and a set of procedures which enable decision makers and developers to examine carefully and systematically the way in which an attack on a social or educational problem might be made. It lays out a schedule of activities and emphasizes the areas in which problems may arise. But system analysis as a tool does not in itself assure the successful outcome of an attack on a problem. *System analysis represents the formalization and procedural expression of the approach that wise, systematic, and successful men have always taken in trying to solve their problems.* [Italics are mine.] In education it has a particular applicability because it places much emphasis on the problems of implementation, evaluation, feedback, and revision—an emphasis which should be highly welcome in today's complex educational milieu.

Figure 4 is a graphical summary of the systems approach from this book.

Finally, educational planners themselves have begun to utilize the systems approach. The *World Educational Crisis. A Systems Analysis* [17] was written by Philip H. Coombs, former director of the International Institute for Educational Planning of Unesco. The aims of this book are twofold.

The first is to assemble in one place the root facts about the world crisis in education and to make explicit their inherent tendencies and to suggest some of the possible elements of a strategy to deal with the crisis. The second aim is to present a method for examining an educational system, not piecemeal where every fact stands alone, but *as* a system—a system with interacting parts that produce their own 'indicators' as to whether the interaction is going well or badly.

An educational system, *as* a system, obviously differs greatly from the human body—or from a department store—in what it does and how it does it and the reasons why. Yet in common with all other productive undertakings, it has a set of *inputs,* which are subject to a *process,* designed to attain certain *outputs,* which are intended to satisfy the system's *objectives.* These form a dynamic, organic whole. And if one is to assess the health of an educational system in order to improve its performance and to plan its future intelligently, the relationship between the critical components must be examined in a unified vision.

Two figures from the book will help spell out the details of what is in the system and how it functions. Figure 4 presents a simplified diagram showing some of the more important internal components of an educational system. Figure 6 shows the multiple inputs from society into the educational system followed by the multiple outputs from that system which flow back into a society upon which they ultimately have many diverse impacts.

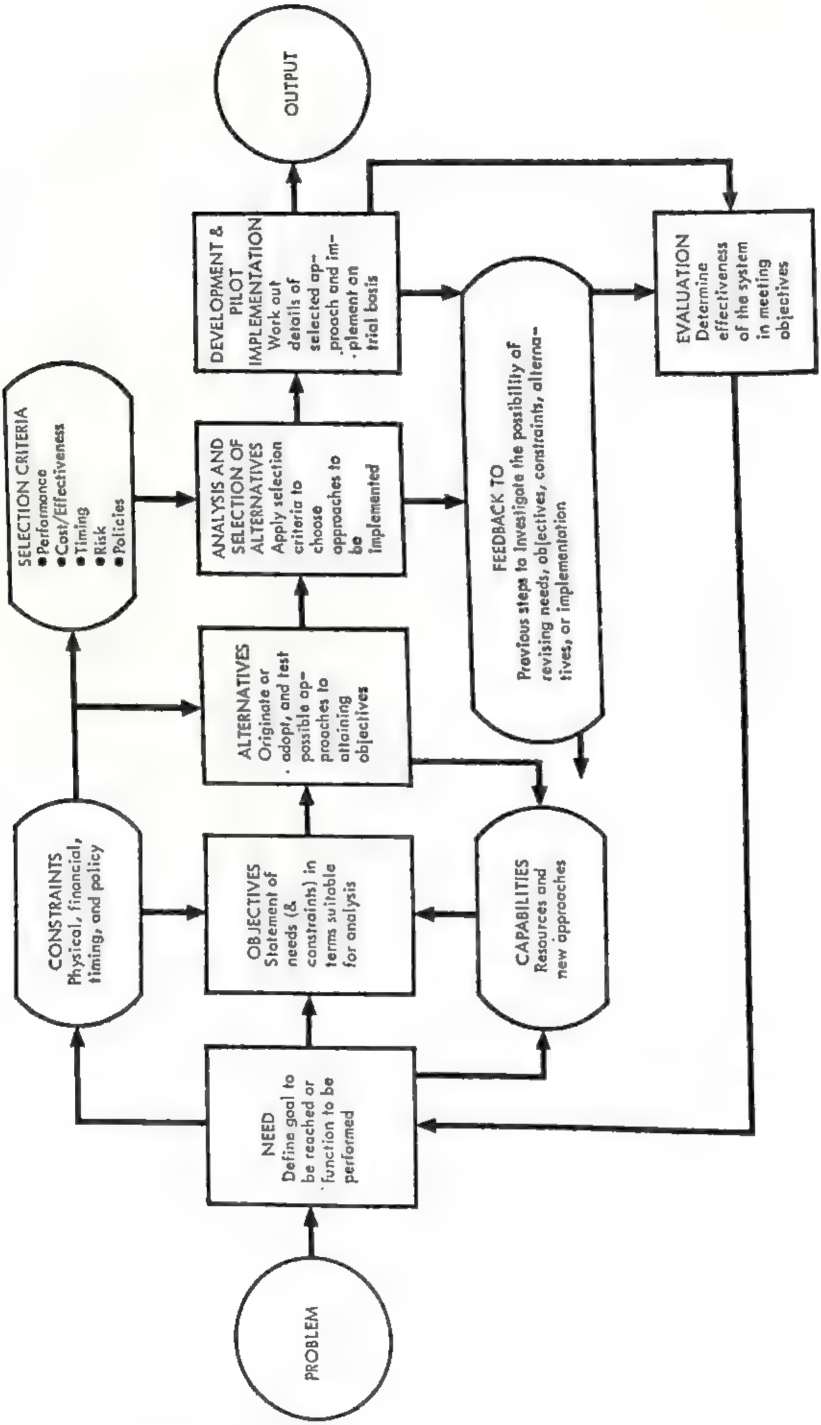

Fig. 4. The systems approach.

Educational process

Resource INPUTS

1. **Aims and priorities**
   to guide the system's activities
2. **Students**
   whose learning is the main aim of the system
3. **Management**
   to co-ordinate, direct, evaluate the system
4. **Structure and time schedule**
   to deploy time and student flows among different purposes
5. **Content**
   the essence of what students are intended to acquire
6. **Teachers**
   to help provide the essence and orchestrate the learning process
7. **Learning aids**
   books, blackboard, maps, films, laboratories, etc.
8. **Facilities**
   to house the process
9. **Technology**
   all the techniques used in doing the system's work
10. **Quality controls**
    admission rules, marks, examinations, 'standards'
11. **Research**
    to improve knowledge and the system's performance
12. **Costs**
    indicators of efficiency of the system

Educational OUTPUTS

FIG. 5. The major components of an educational system.

Educational technology and the systems approach

Educational technology will be dealt with in the next chapter but we may note here that there is a close relation, at least from a philosophical and operational point of view, between systems analysis and educational technology.

Educational technology means more than the use of technology in education. It means more than just the totality of teaching aids available. It now often implies a systematic development of teaching-

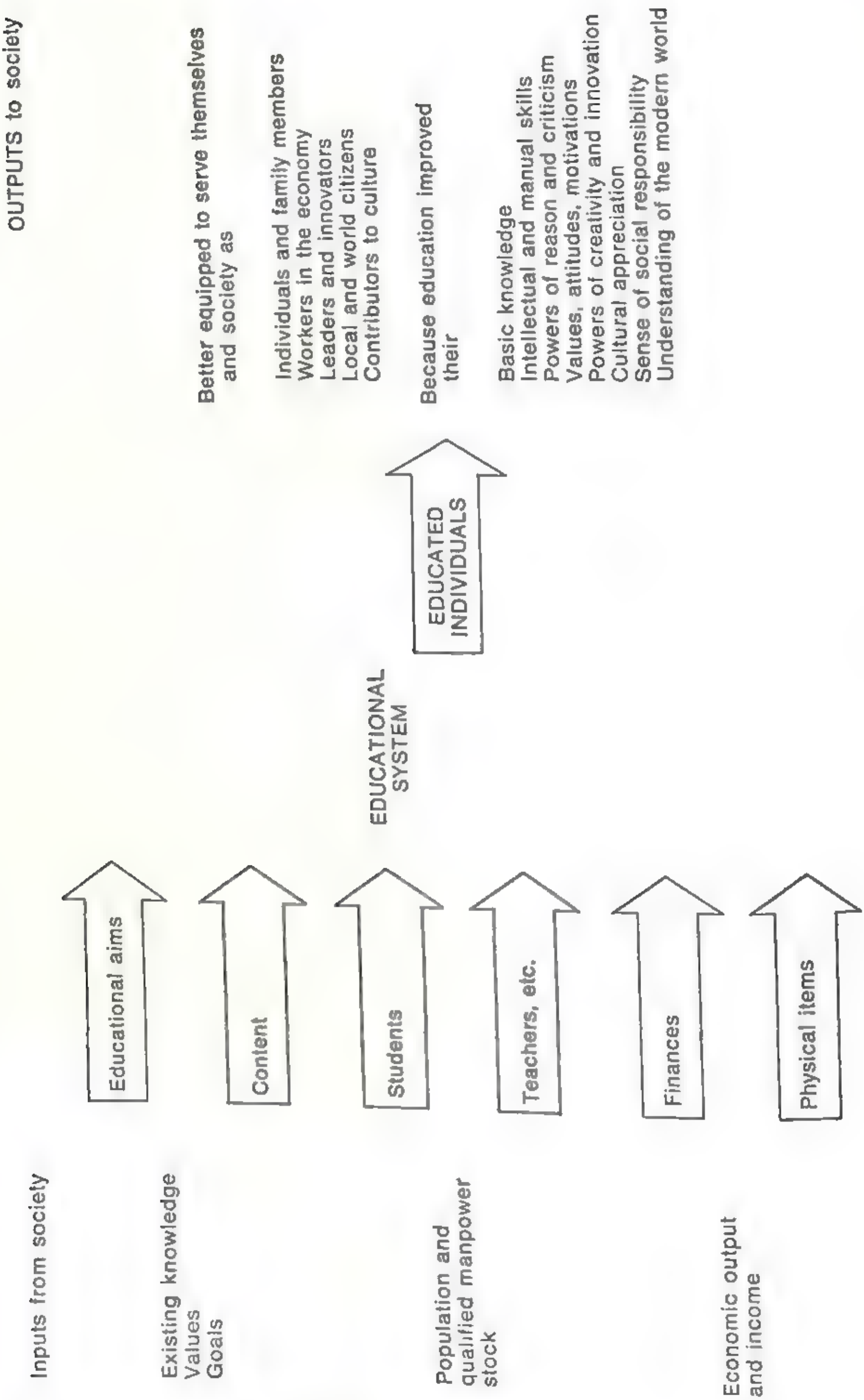

FIG. 6. Interactions between an educational system and its environment.

learning strategies which have the following in common: (a) they begin by stating in advance what the student should be able to do in the end that he was not able to do at the start, and (b) they culminate in an assessment which measures the success of the operation in terms of how well the student achieves what the planner—in this case the educator with the help of the educational technologist—said he should be able to achieve.

In principle, then, what the educational technologist is supposed to be able to do is to choose the particular combination of approaches, methods, materials and media which in his judgement will maximize the probability that the student will learn; that is, achieve the prescribed objectives.

A single course within the total system can, obviously, be treated as a subsystem to which the approach of educational technology and hence of the systems approach is applicable.

Possibly the most important use to which the systems approach has been put at the university level has been at the Open University of the United Kingdom. It is the only university in which every course has been designed using the systems approach. To ensure this, an Institute of Educational Technology has been created within the university and it occupies a central position between its six faculties (arts, educational studies, mathematics, science, social science and technology) and the service units of the university to assist in developing the correspondence core and other elements of each course. Educational technologists from the institute are active members of each course team. They advise on the design and structure of courses, they write tests for each section of the course and they arrange and conduct trials of course components. The members of the institute supervise the over-all development of the instructional system of the university, treating it as a system in which information from the students is stored in a computer, retrieved, and utilized to improve the courses on the basis of this feedback. The analysis and synthesis of all the subsystems necessary to produce this instructional system for the Open University are among the functions of its Institute of Educational Technology.

The systems approach to science education

From what we have said it is clear that since science is a subset of the total curriculum the systems approach can be applied to it. An interesting example of this at the high school level is described by Bixby [52]. I have chosen this example because it also touches upon two other concerns dealt with in the present book, namely, relevance and social responsibility and integrated science. The integrating concepts chosen are energy, structure and life so that an interdisciplinary approach was necessary. Bixby describes how he and his colleagues

went about devising a course with goals that reflected their philosophy. They went about generating their course

> by identifying the problem, defining objectives that must be achieved to solve it, considering alternative methods for meeting these objectives, and choosing the most attractive alternatives by rigid analysis by intuition and judgement, or by something in between

which are indeed some of the activities we have associated with the systems approach. Further details on the systems approach will be found in Chapter 6 under educational technology.

The trend towards integrated science education

A strong world-wide movement

There has been so much activity in the area of integrated science round the world in the last few years—experimental courses, for example, have been tested in many countries—that it now looms as one of the strong and significant trends in modern education. Two international conferences on the subject have been held and three separate volumes on integrated science have appeared in the Unesco 'New Trends' series [53]. There is, consequently, probably no better way to illustrate the magnitude and direction of this world-wide movement than by referring to the work of these conferences and to the contents of the Unesco 'New Trends' series dealing with integrated science in which many of the new courses are described.

In this chapter—leaning heavily on these Unesco volumes—I will discuss what the term integrated science means, why it is needed and some of the problems that arise in its implementation. I will also give some other sources of information on the subject but specific examples of integrated science projects will be deferred until Chapter 6.

The first international conference alluded to—the Congress on the Integration of Science Teaching—was held in Droujba (Bulgaria) in 1968. Droujba is near Varna and the conference is sometimes referred to, loosely, as the Varna Conference.[1] It was organized by the International Council of Scientific Unions (ICSU) through its Inter-

1. Copies of its final report may still be available from D. G. Chisman, The British Council, 10 Spring Gardens, London W.C.1 (United Kingdom).

Union Commission on Science Teaching with the support of Unesco and the Ford Foundation.

A great deal of time was spent at this conference trying to define the concept of integrated science by examining carefully just what was being done under this banner by its many practioners round the world. It was found that the term 'integrated science' meant different things to different people but there was a general agreement that, even defining integration loosely, teaching science in an integrated way would seem to have some benefits in certain situations and should therefore be promoted. It was recognized, however, that there would be no widespread acceptance of the integrated approach unless teachers were adequately prepared for it. It was recommended, therefore, that the training of teachers for integrated science should—after allowing a suitable interval of time for experimentation to take place—be the topic of a subsequent international conference.

Five years later, in 1973, the second conference was held at the University of Maryland. It was called the International Conference on Education of Teachers for Integrated Science, and was again organized by ICSU, this time through its Committee on the Teaching of Science (successor to the Inter-Union Commission of Science Teaching), in collaboration with Unesco, the University of Maryland and the United States National Commission for Unesco. It also had substantial support from many other organizations.

In the five years that had intervened between the two conferences, activities and interest in integrated science world-wide had increased to such an extent that it was not difficult to convene more than 200 participants from 63 countries to spend 10 days working at the University of Maryland on the problems related to the preparation of teachers for integrated science. The reader is referred to the final report of the Maryland Conference [54] as a brief summary of the events that took place and to the third volume in the Unesco 'New Trends' series dealing with integrated science for detailed proceedings, reports of the working groups and a summary of discussions and comments at the plenary sessions [53]. We shall have more to say about the contents of the three Unesco volumes on *New Trends in Integrated Science* when we discuss sources of information.

Integrated science—a dynamic concept

Despite all this activity, the concept of integrated science can still not be cast into a simple and definitive verbal mode. The basic reason is that it is a dynamic concept. It is still adjusting to what people do when they say they are teaching science in an integrated way.

Nevertheless, at a co-ordinating meeting of Unesco's programme in integrated science teaching, held in 1972, the following definition emerged:

Integrated science teaching consists of those approaches in which the concepts and principles of science are presented so as to express the fundamental unity of scientific thought and to avoid premature or undue stress on the distinctions between the various scientific fields.

This wordy pronouncement has been described by a scientist friend of mine as 'a fine example of educationists rhetoric', yet no better single statement has emerged. It has occasionally and informally been referred to as Unesco's definition of integrated science teaching but it was hardly the intent of Unesco to give it the air of an official definition; no one is more aware of the dynamic character of integrated science than the project officer in charge of this programme at Unesco.

Some of the refinements which have taken place in the concept are exemplified by the following quotations from the article by Rutherford and Gardner in Volume I of Unesco's *New Trends in Integrated Science Teaching* [57].

The concept of integrated science teaching is necessarily based on various assumptions about the natural world, science and education. One of these, usually implicit, is that the universe itself is somehow unified. As a matter of faith, rather than as a conclusion based on evidence, most scientists and, indeed, most individuals, believe that in some sense the natural world is of a piece. . . . While the present imperfect state of our knowledge forces us to describe various aspects of the real world in the restricted language of this or that science, we tend to believe that any seeming disunities are due to the limitations of such descriptions and not to the 'reality' itself.

Another assumption implicit in the concept of integration of science is that 'science'—as distinguished from 'nature'—is coming to be regarded as unified in substance and content. According to those who hold this belief, a final set of logically related laws and theories will eventually exist to explain all natural phenomena. . . .

Thus, to some degree the concept of integrated science teaching is based on the parallel assumptions that the universe has an inherent unity and that science as an attempt to provide an understanding of the natural world has a unity of purpose, content and process that is far more significant than the difference in language or forms between individual sciences. If the natural sciences are becoming unified methodologically, then, according to this assumption, science teaching should emphasize this by itself being integrated.

Another way of looking at integrated science teaching is to say that it is the way one would naturally introduce science to children. In the field or in the classroom you lead them to take the first steps which a scientist would take in approaching nature. You stimulate their curiosity and you show them how, by observing carefully and systematically and then thinking about their observations and letting new questions arise from them, they can pursue the matter in search of understanding—exactly what the scientist does—without ever labelling any of their activities 'physics', 'chemistry' or 'biology'.

In this vein a group of African educators [55] came up with the following statement in response to the question: 'What is an integrated approach to learning?'

Integration is a fundamentally different approach to learning. In programmes of this kind, an attempt is made to follow the child's natural way of learning. The teacher accepts (with the child) that the world around us must be viewed as a whole. The world around the pupil invites many questions and poses many problems. The questions become more complex as his knowledge increases.

In answering these questions and solving the problem he is driven to develop a number of general and specific skills. The basic skills are those of observing things carefully so that he can extract the maximum information: recording things in various ways so that he can retain the information and pass it on to others, and thinking about the information he has gathered so that he can draw conclusions, and plan further action.

These statements view the problem of integration from the point of view of the learner. From the teacher's point of view the article continues:

When a teacher bases his work on an integrated approach he accepts that his role is: (a) to provide the kind of experiences which will lead children to ask questions; (b) to provide materials (or suggest sources for them) for pupils to record things they have observed. . . . Materials will also be required for experiments which the pupil wishes to carry out. Many of these can be located after suggestions have been made by the teacher; (c) helping pupils in the process of finding out and suggesting further lines of enquiry.

At the same conference, another participant, E. A. Yoloye said:

What science can do is to give the child the kind of preparation that will help him to benefit from such training. With this aim in mind, great care should be exercised in the selection of topics for inclusion in the science curriculum. Work on germination or the nature of soils would be relevant topics; because malaria and malnutrition are big health hazards in African countries, a study of mosquitoes and nutrition appears relevant. Given the basic hypothesis that a child is potentially capable of working with any topic, concern for the needs of society should guide the selection of topics. More important, however, is the development in the child of a realization that he can manipulate and control his environment; that he need not be the helpless victim of a changing society, but can become an innovator, capable of changing society.

These are much more ambitious and, incidentally, worthy goals for science education than the old ones which stressed rote memorization of facts. Note in particular the emphasis on and concern for the needs of society.

These quotations make a good case for the integrated way as the

natural way to teach children, but it is not so clear how far up the educational ladder an integrated approach can or should be used. In the next chapter we shall give examples of projects at the elementary secondary and post-secondary levels.

For those who will eventually specialize in one field of science, however, it seems obvious that at some level, some courses will have to be taught in the separate disciplines. It seems natural to imagine that, at the highest level of graduate studies, a study in depth of some specific problem of topic is preferable to integration. So between complete integration at the primary level and complete separation at the graduate level one can imagine a spectrum which includes different varieties of integration, co-ordination and separation of the scientific disciplines.

At all levels, including the introductory courses at the university level, the broader educational needs of those students who will not specialize—and they are in the majority—would seem to be better served by courses which use an integrated approach, especially now that we are conscious of the need for relevance in education.

A more cautious approach was advocated by Goodlad at the Maryland Conference [56]:

I am not at all sure that the current zest for integrated science, social science, or humanities is equally beneficial for all phases of schooling. It seems eminently reasonable that the very young should be introduced to concepts such as size, weight, shape, and relatively quite apart from what would be for them the burdensome structure of each discipline. It seems equally reasonable that children of an older age should arrive at physical and ecological principles through the study of machines and ponds. But it may be that science in a subsequent phase of schooling can be approached effectively through a single discipline, ever mindful of the relevance of its methods and concepts to the physical world in which the students live.

The content of integrated science courses

The selection of content for integrated science teaching is discussed by Rutherford and Gardner [57] as follows:

The scientific content of a given integrated science course may appear as a consequence of how the course is designed. In practice, the final selections usually involve both *a priori* decisions and decisions made on the basis of the organizing principle used to guide the shaping of the course. In any case, it is useful to think of integrated science as being of four kinds:

1. Those that integrate the subject matter from various subdivisions of a major science. . . . (One example is the general introductory chemistry course based on material taken from inorganic, organic, and physical chemistry. Another example might be the physics course that treats physics as a unified structure of ideas rather than

as essentially separate courses in classical mechanics, heat, light, sound, electricity, and magnetism, etc.)

2. Those that blend two or more sciences in similar proportions. . . . (It is not uncommon, for example, for 'earth science' courses to place roughly equal emphasis on astronomy, meteorology, oceanography, physical geography, and geology. Some, such as the ESCP course, *Investigating the Earth*, try to truly integrate the content, but many are no more than separate units joined by a name into a co-ordinated course.)
3. Those that blend two or more sciences together, but with a strong bias toward one. . . . (Thus, both the Physical Science Study Committee (PSSC) course and the Harvard Project Physics (HPP) course are labelled 'physics', but both of them contain a considerable amount of material of the sort that would ordinarily be considered chemistry and astronomy. The difference between this and the previous category is essentially a matter of emphasis.)
4. Those that select content as described in any one of the above three categories, but in addition integrate material from the non-sciences. . . . (In this group are courses that pay attention to the philosophical underpinnings of science, to the development of scientific ideas and to the social consequences of science and technology.)

Under methods for organizing integrated science teaching the same article continues:

For many years in the United States, there have been in use in many schools courses and books going by the title 'General Science'. It was frequently claimed that these were essentially integrated science courses because they contained content from many different sciences; in fact, most of them were nothing more than collections of short units in several of the individual sciences. Such a course cannot be thought of as integrated science according to the definitions agreed upon at the Varna Conference and implicit in this report.

In order for a course or program to be considered truly integrated, it is necessary that 'the concepts of science are presented through a unified approach'. A unified approach can be designed in a variety of ways.

The authors continue by discussing at considerable length the following four approaches: the conceptual schemes approach, the inquiry approach, the relevance approach, the process approach.

The interested reader is referred to their article for an elaboration of these terms. Specific examples of projects that illustrate them will appear in Chapter 6. For another opinion on the matter see the article by William C. Hall entitled 'Case Study in Curriculum Decision Making: The Schools Council Integrated Science Project' [58].

Reasons for teaching science in an integrated way

In 1969, when Unesco launched its programme on integrated science, there was widespread concern that school science courses should not be conceived, as in the past, solely or mainly as a preparation for the pursuit of scientific studies at a higher level. Besides this negative argument there are positive arguments in favour of teaching science in an integrated way, some of which have already been suggested in the above attempts to define integration—these and others fall into one or more of the following categories:

Philosophical. Since nature is unified, science can also be unified and so can the teaching of science. This gives coherence to scientific knowledge.

Economic. It is possible to avoid some unnecessary duplications. Topics such as the kinetic theory of gases, the structure of the atom and nuclear energy appear in both physics and chemistry courses. Introductory biology courses usually contain units on such physics and chemistry topics as capillarity, osmosis and fluid pressure. These and other topics could be treated in an integrated way. It is of particular importance to poor countries to reap the economic benefits of teaching science in an integrated way.

The growing need for generalists. In modern society there is a growing demand for educated non-specialists who have become aware of the methods, power, relevance and limitations of science and its great potential for the improvement of society. It would seem that an integrated approach to science education would serve the needs of this great majority of students better than the conventional approach in which the contents of the scientific disciplines are kept apart. Even at the tertiary level it has been shown to be possible and in some cases desirable to teach science in an integrated way for the benefit of non-specialists.

The special needs of the developing countries. Most developing countries are in need of the benefits of science and technology. One of these benefits is an attitude engendered by a proper study of science holding that the universe is knowable and that problems are solvable. But most children in developing countries receive only an elementary school education. If their outlook is to be infused with the spirit of science it has to be effected in the primary school. Whatever they are to learn about scientific attitudes and approaches to problem solving has to be learned in the primary school. Fortunately, this is the level at which an integrated approach to science teaching is most natural but, of course, special materials must be prepared for it and teachers must be properly trained to teach in an integrated way. At the lower secondary level the economic benefits of integrated science may be significant. It may not be necessary to have

both a physics and a chemistry teacher if science is taught in an integrated way. Science courses must be designed which are not only foundation courses but terminal courses as well. They may be the pupils' only formal scientific preparation for adulthood.

The needs of the learner. There is a growing awareness that the psychological, social, physical and emotional needs of the learner may be better met by teaching science to him in an integrated way than in the old separated way. Psychologists have discovered that there is a 'logic of the child' which differs from the 'logic of the subject' so that courses need to be designed in relation to the child's intellectual development. More generally, it could be said that there is a 'logic of the learner' at all ages which must be taken into account. The economic factor may be reinforced if one considers that the student learns more effectively when he learns science in an integrated way.

The needs of society. The needs and aspirations of society for the benefits of science and technology may, perhaps, be better met by an informed citizenry that has been exposed to science in an integrated way. Their better grasp of the whole picture of science may enable them to grapple with the decisions that society needs to make on the applications of science to human welfare.

Unesco's activities in integrated science teaching

At its General Conference in 1968, Unesco launched a programme in integrated science teaching. Space does not permit giving details here. They may be obtained by writing directly to the Director of the Division of Pre-University Science and Technology Education, Unesco, 7 Place de Fontenoy, 75700 Paris (France).

Briefly, the programme has four main parts comprising (a) publications, (b) workshops on a regional, subregional and national basis; (c) stimulation of pilot experiments on curriculum development and teacher training in Member States; and (d) advisory services.

The first workshop was held in Israel in 1969 within the framework of the Rehovot Conference on Science and Education in Developing States. In 1970 a national workshop was held in Ghana.

The first regional workshop was held in the Philippines in August 1970. It included participants from twelve Asian countries. Similar regional and subregional workshops have been held in Africa, Latin America, the South Pacific and Caribbean regions.

The project at Tel Aviv University is an example of a national activity. It is linked with the Israel National Science Teaching Centre which received some support from Unesco in its formative stages. The materials being developed, while drawing resources and inspiration

from similar projects in the United States are essentially indigenous in nature.

In Ghana, the 1970 workshop launched the 'Project for Science Integration', a major national project, under the joint auspices of the Ministry of Education and the Ghana Association of Science Teachers. This project is producing educational materials for primary, secondary and teacher training curricula.

In the Philippines, work on the production of an integrated junior high school course has started at the Science Education Centre at the University of the Philippines.

These are just a few examples of Unesco's activities. For updated information the reader is referred to Unesco Headquarters.

Sources of information on integrated science

No attempt will be made here to give an extensive bibliography. The reader is referred, instead, to two sources already cited which, if properly researched, will yield a great deal of information.

The first of these two sources is the three volumes of Unesco's *New Trends in Integrated Science Teaching* [53].

Volume I (1969–70) contains an introduction to integrated science in the form of commissioned articles as well as articles reprinted from other sources such as the 1968 ICSU Varna Conference and the 1967 EDC and CREDO Conference of African Educators. It also contains many examples of projects which illustrate different approaches to integrated science teaching and a section on social and psychological questions. It focuses primarily on the elementary level of schooling.

Volume II (1973) contains nine commissioned articles which describe the existing condition and future trends in aspects of integrated science teaching throughout the world. It includes schemes ranging in level from elementary to the university levels. The articles deal with aims, objectives, rationale, content, approaches and methods. They also deal with low-cost materials, integrated science in tertiary education, environmental education, evaluation and integrated science as part of general education.

Volume III (1974) contains the proceedings of the ICSU Maryland Conference on Education of Teachers for Integrated Science. It contains summaries and conclusions of the deliberations of eight working groups and the text of eleven plenary presentations with a summary of subsequent discussions. It has four main sections entitled: Integrated science and the science teacher; The pre-service and in-service education of science teachers; The improvement and evaluation of teacher training programmes for integrated science; and The social significance of science. The last topic is related to the subtitle of the conference: 'Teaching Science for Today's Society'.

The second source is the *Eighth Report of the International*

Clearinghouse on Science and Mathematics Curricular Developments, 1972 [24].

This report, edited under the direction of J. David Lockard of the University of Maryland, contains a description of thirty integrated science teaching projects outside the United States and sixty-five projects within it. It gives information on, among other things, the director, headquarters, staff, support, history, objectives, characteristics, materials, evaluation and plans for the future. It is all in summary form but enough information is given so that interested parties can communicate directly with project officers to obtain further details.

The trend towards the establishment of permanent institutions devoted to science education improvement

This section gives a sampling—by no means complete—of the types of institutions that have arisen in the wake of the science curriculum improvement movement.

As we said earlier, however, in certain parts of the world, notably Eastern Europe and parts of Western Europe, pedagogical institutes charged with the task of continuing improvement of all educational practices, including those in science, have been in existence for a long time. We wish to document instead the transition from isolated science curriculum and materials projects to permanent institutions devoted to reform and improvement in science education.

We have in mind institutions whose titles include words like 'centre' or 'institute' indicating that they are more permanent than those properly called simply 'projects'.

These centres are devoted to educational research and the development and testing of new materials: books, teachers' manuals, self-instructional aids, films and experimental kits. Some also devote part of their time to pre-service or in-service training of teachers and science supervisors. Some attempt to reach an out-of-school audience, including both children and adults, for the purpose of stimulating an interest in science and its constructive societal applications.

No single source of information devoted to such permanent institutions has come to my attention but the *Eighth Report of the International Clearinghouse on Science and Mathematics Curricular Developments, 1972* [24] to which we have referred from time to time

does contain some information about permanent centres. This appears only incidentally, however, since the report is mainly about projects. It is embedded in an information matrix in which individual projects are highlighted.

One category of such institutions is funded by international sources like the United Nations Development Programme (UNDP). Another type of institution is funded by national sources such as the National Science Foundation in the United States. Whenever the source of funds is explicit, information about the institution is available directly from the funding agency.

Some centres in the United States

In the United States, information on centres may be obtained from the sources already cited and also from the Commission on Science Education of the American Association for the Advancement of Science.

I will limit myself to three institutions—two on the east coast and one on the west coast—but I will also give names and addresses of a few others.

As we said in an earlier chapter, science teaching improvement in the United States during the last fifteen years was characterized broadly by large projects in the separate disciplines of physics, chemistry, biology, and mathematics. These projects, incidentally, also provided great stimulus to reform in areas other than science education. As the original support for them diminished, other means were sought to continue their work on a permanent basis. Some science teaching centres, in other words, grew out of expanded projects.

A good example of this is afforded by the evolution of the Educational Development Center (EDC) of Newton, Massachusetts, which grew out of a project devoted mainly to physics. It is, perhaps, the most striking example of how reform in science education can spearhead reform in education as a whole.

Educational Development Center (EDC)

This is a private, non-profit corporation engaged in educational research and development. With the support of foundations, government agencies, business and industry, EDC conducts a wide variety of projects in the United States and overseas.

It was formed in 1967 by the merger of two other groups: Educational Services Incorporated (ESI) and the Institute for Educational Innovation (IEI). EDC currently administers a number of projects in curriculum and school development. Originating with the formation of PSSC these projects range from pre-school to university levels.

Although in the beginning the main focus was on one project in physics, the table of contents of the 1973 *Guide to Project Activities and Materials* lists over fifty different projects covering a broad range of activities in the areas of science and mathematics, films, social studies, open education, international education and career development. Information is available from EDC, 55 Chapel Street, Newton, Massachusetts.

An idea of the magnitude of the EDC operation is given in the treasurer's report for 1969. During the fiscal year ending 30 September 1969, EDC received over $6.5 million in new contracts and grants. The total received by EDC since its inception in 1967 to 1969 was over $63.3 million. It was still active in 1974.

University of Maryland Science Teaching Center (STC)

The functions of the Science Teaching Center (STC) include teacher and supervisor education, graduate education, basic research in science education and consultative services.

Some of the special projects carried out by the STC staff include: preparation and publication—since 1963—of the international clearinghouse reports on science and mathematics curricular developments, collection and maintainance of sample materials from numerous science and mathematics curriculum projects throughout the world, publication of a four-year *Study on Improvised Science Teaching Equipment—Worldwide* culminating in three guidebooks to constructing inexpensive science teaching equipment: *Biology, Chemistry* and *Physics*.

Other projects include: reviewing activities of the National Science Teachers Association's Science Materials Review Committee; the Chemistry Teaching Associates Program; the Academic Institute for Science Supervisors; in-service and summer institutes in the biological, physical and earth sciences; co-operative college-school programmes; leadership conferences and special conferences for national, state and local groups.

The facilities include two well-equipped science teaching rooms used for methods courses, a research and special projects room, a vivarium, an extensive science education library, preparation rooms, photography dark-rooms, and the international clearinghouse permanent collection room.

The Science Teaching Center shares facilities with the Educational Technology Center, including a construction shop, graphic arts shop, audio-visual centre, audio-tutorial centre, ETV centre and multimedia rooms. It has close ties with other departments on campus, particularly with the science departments where faculty members hold joint appointments in botany, chemistry, geology, physics and astronomy.

It is host to many foreign and domestic visitors and was the

seat of the ICSU International Conference on the Education of Teachers for Integrated Science held in 1973. It works closely with the Commission on Science Education of the American Association for the Advancement of Science (AAAS) and receives support for some of the activities from the National Science Foundation and other sources.

The Lawrence Hall of Science

The Lawrence Hall of Science is a national centre for research and teacher training in science education. Its original broad aim was to help 'raise the scientific literacy' of the nation. Glenn Seaborg, former Chairman of the United States Atomic Energy Commission and Chancellor of the University of California at Berkeley is regarded as the 'father' of the Hall of Science for it was he who met with the regents and others to shape the first ideas for it. Harvey White, a professor of physics at Berkeley, was appointed to direct the centre. He saw that the Hall of Science could exercise a constructive and far-reaching influence on the future of California and of the nation. White was recognized as an outstanding and dedicated teacher—in 1958 he pioneered the first national televised course called *Continental Classroom*—and his practical and imaginative ideas guided the Hall of Science during approximately the first decade of its existence.

It has spacious shops, lecture halls, exhibit areas and facilities for experimenting with all the media of modern educational technology.

Today it is carrying out a vigorous programme under Watson Laetsch, its present director, in three broad areas: (a) public programmes and school activities; (b) teacher training; and (c) research and curriculum development in science education.

Public programmes and school activities cover: activities and exhibit areas, classes, lectures and films, science education library, special groups and symposia, planetarium, school visitation, mathematics and engineering, and computer services. Total annual budget: $292,000.

Teacher training covers: teacher-initiated projects, discovery van, education for the disadvantaged, engineering concepts, summer classes, internship programme in science education innovation (with Unesco), Saturday workshops, and a teachers' centre. Total annual budget: $779,000.

Research and curriculum development in science education includes: Science Curriculum Improvement Study (SCIS), adapting SCIS for blind students, Advancing Education through Science Oriented Programs (AESOP), Outdoor Biology Instructional Strategies (OBIS), Chemical Education Material Study (CHEMS), experimental investigation of peer teaching, science teaching with television, computer languages, research on the

effectiveness of an exploratory environment and science and technology exhibits and activities. Total annual expenditure: $1.2 million.

The grand total is $2.3 million.

Some other United States centres

The large number of centres precludes discussion or even enumeration here. Current information on such centres is available from the Office of Education of the American Association for the Advancement of Science, 1776 Massachusetts Avenue NW, Washington DC 20036 (United States).

Some centres in Western Europe

There are two important activities in Europe which should be mentioned initially even though they are not, properly speaking, science teaching improvement centres. Both have interests broader than science education but both have made important contributions in the area of science teaching improvement.

Centre for Educational Research and Innovation (CERI)

CERI is an activity of the Organization for Economic Co-operation and Development (OECD). OECD has nineteen Western European member countries plus Australia, Canada, Japan, New Zealand and the United States. OECD made significant contributions to curriculum development in science and mathematics at the secondary level in the years preceding 1966 but began shifting emphasis to broader curriculum improvement and educational development activities in OECD countries around that time. Out of this concern CERI was established in 1968 with a grant of $1 million from the Ford Foundation later supplemented by a grant of $750,000 from the Shell Group of companies. CERI's programme grew out of the realization that quantitative growth of education cannot be fully realized without fundamental qualitative changes which in turn depend on educational research and innovation. Recently CERI has entered the field of assessment of educational innovations. Information may be obtained by writing Centre for Educational Research and Innovation, OECD, 2 Rue André Pascal, 75016 Paris (France).

Centre for Educational Development Overseas (CEDO)

CEDO is a British organization created in 1970 to assist developing countries with modernization and innovation in education. The activities of CEDO are now being carried out by the British Council but

I shall adhere to the name CEDO because that is how it will be found in the literature. It is supported by funds from the British Government and is assisted in its activities overseas by the British Council.

In science education it has assisted developing countries by providing information, advice and help. Recent interest has, for example, given rise to projects in integrated science in the Caribbean, in Sierra Leone and in Botswana, Lesotho and Swaziland. CEDO has also acted as a consultant to Unesco and Unicef in primary and middle school science in India. Although much of CEDO's efforts are directed toward Commonwealth countries it is also operating in Latin America, the Middle East and in the Far East. Information is available from D. G. Chisman, The British Council, Tavistock House South, Tavistock Square, London, W.C.1 (United Kingdom).

Centre for Science Education of Chelsea College of Science and Technology

This is a good example of a science teaching improvement centre. It grew out of the efforts of the early Nuffield projects and exemplifies how activities that begin as projects can later be institutionalized in order to guarantee that improvement activities will continue on a more permanent basis.

The centre has brought together the workers in ongoing projects funded by the Nuffield Foundation, in physics, chemistry, biology, mathematics, physical science and secondary science. They prepare materials such as books, teachers' manuals, films and other visual aids. They conduct courses for pre-service and in-service training of teachers and implement the projects, often trying out their materials with tens of thousands of pupils in hundreds of schools. Information is available from the director, Kevin Keohane, Centre for Science Education, Bridges Place, London, S.W.6 (United Kingdom).

Institut für die Pädagogik der Naturwissenschaften (IPN)

This institute of the University of Kiel, Federal Republic of Germany, was established to develop a science programme for the early grades in that country. The need arose because traditionally the teaching of science in the schools of the Federal Republic begins some years later than it does in the school systems of many other countries. IPN professional staff includes faculty members from the departments of education and evaluation as well as from the departments of biology, chemistry and physics of the University of Kiel. IPN is also concerned with developing materials for teaching science at higher grades and with the training and retraining of teachers.

Materials prepared for teachers include teachers' guides for experiments, instructions for administering tests, tables and graphs for interpreting test results, and equipment for demonstration experiments.

In each programme, development of materials goes through a cycle of writing, testing and revision before being published for wide use in schools. A group of IPN curriculum specialists from all departments is investigating the possibilties of co-ordination of the curricula for physics, chemistry and biology. Information is available from Professor Dr Karl Frey, IPN, Neue Universität, Olshausenstrasse 40, 23 Kiel 1 (Federal Republic of Germany).

These and other centres are described in the eighth [24] and ninth reports of the International Clearinghouse of the University of Maryland.

Eastern Europe

We have already described the pattern for course content improvement, curriculum reform and the introduction of new approaches, methods and techniques in science teaching in some of the Eastern European countries.

These activities are carried out in pedagogical institutes and academies of pedagogical sciences. They seem to have broader powers and support than, say, the schools of education found in the United Kingdom or in North America.

Some centres in the developing countries

Centres established with assistance from the United Nations Development Programme

With the experience gained in running its pilot projects in the separate sciences of physics, chemistry, biology and mathematics, Unesco began promoting the creation of permanent national institutions devoted to the continuous improvement of the teaching of all the sciences. Assistance from the United Nations Development Programme (UNDP) in the funding of these projects was sought by several countries with the help of Unesco.

The specification of the objectives and a detailed working plan for each institution took several years of work, in some cases requiring several joint UNDP/Unesco missions and many meetings with the responsible officials in each country. The pattern of the centre that developed varied from country to country because of differences in their size and economic and social conditions and such factors as the status of existing science education improvement projects within the country.

UNDP exists to assist in institution building but a request has to come from the government of the interested country with a proof of earnest intent, indicated by putting the creation of a science teach-

ing centre high on the list of priorities for UNDP requests by that country and a willingness to match or exceed the UNDP funds.

UNDP support also depends on their acceptance of the proposed objectives, programme, staffing, timetable and budget. Since Unesco is the Specialized Agency of the United Nations with competence in science and education, the project, if approved by UNDP, is administered by Unesco. The tasks of such centres were first described in a note by Unesco (AVS/DST/1967/49 of January 1967) entitled 'National Science Teaching Centres—A Scheme for Reform in Science Education'. The three main tasks listed there are (a) analysis of basic content of each science; (b) development of sound laboratory experiments; and (c) preparation of modern teaching aids. In subsequent years the objectives and functions of these centres have evolved considerably. Most of them also have a strong teacher training component to ensure that the new ideas, methods and materials are properly utilized in the schools. Here are some brief notes on two such centres.

Israel Science Teaching Centre. An initial proposal for a centre was submitted by the Government of Israel to UNDP in 1967. It requested a total of $1.1 million of UNDP assistance in the form of experts, fellowships and equipment; and proposed to match this with $2.2 million for counterpart personnel (professional, technical and administrative), land, buildings, equipment and operating funds.

The drafting of the proposal had involved extensive consultation with Unesco over a period of several years. Professor Amos de Shalit, Director of the Weizmann Institute of Science in Rehovot, had taken a personal interest in the project and had made initial overtures by discussing his ideas with Unesco. The form in which UNDP assistance was eventually tendered differed from that of the initial proposal: it became a smaller project in which UNDP assistance over five years was to total around $450,000 with a government contribution of nearly $600,000.

The centre was officially established by Israel in 1968 and has ever since been increasingly active in the process of innovation and in improving all aspects of science education at the primary and secondary levels. It has a decentralized structure, with teams working at the Ministry of Education, at the Weizmann Institute of Science, at the University of Jerusalem and at the University of Tel Aviv; and is now known as the Amos de Shalit Science Teaching Centre (in honour of Amos de Shalit who died prematurely in 1969). Being firmly established, the centre no longer receives UNDP/Unesco assistance and now has a yearly budget of about U.S.$700,000 with funds coming from the four institutions mentioned above.

Thailand—Institute for Promotion of Teaching Science and Technology. Bangkok was the headquarters for Unesco's Pilot Project on the

Teaching of Chemistry in Asia, which began in 1965. The developments in Thailand were the first to illustrate the hoped-for transition from a pilot project in one science to an expanded activity with two or more sciences to, finally, a national centre for the improvement of teaching in all the sciences.

In 1969 Unesco sent an exploratory mission to Thailand to conduct discussions with government officials and to determine their readiness for participation in a national science teaching centre. Its report contained suggestions to the Government of Thailand for action in preparation for the drafting of a request for assistance from UNDP. The government submitted its request to UNDP and was granted assistance starting 1971. The title finally chosen for the centre was Institute for Promotion of Teaching in Science and Technology.

The objectives of this centre are:

1. To produce student texts and teachers' guides for science and mathematics at secondary level.
2. To design equipment and stimulate local production.
3. To improve in-service and pre-service teacher training in keeping with the above.
4. To set up a research component on curriculum development.

In taking the steps that finally led to the creation of this centre, Unesco learned a great deal about how to provide national and regional assistance in the area of science teaching improvement. This included the establishment of study groups in different countries of the Asian region, the planning and running of the Asian Regional Pilot Project in Chemistry Teaching held in Bangkok, the creation of a Thai unit to continue similar work in physics and other areas, and, finally, the creation of a national centre for all the sciences. Steps have also been taken to make it possible for this centre to co-operate in science teaching improvement activities in other countries of the Asian region.

Brazil and Venezuela. Examples could also be given of national institutions for the improvement of science education which have been strengthened or established with the participation of Unesco, but without any financial input from the UNDP.

In 1970 Unesco assisted the Government of Brazil in designing a national programme for the improvement of science teaching through strengthening the already existing Fundação Brasileira para o Ensino de Ciências (FUNBEC) and a network of centres for the training of science teachers. FUNBEC arose, as we have said earlier, from IBECC (São Paulo), founded in 1952 by Dr Isaias Raw. It has received support from the Brazilian Government, from the Fundação de Amparo a Pesquisa and the State Secretary of Education of the state of São Paulo, from the Brazilian Development Bank, and from foundations such as Ford, Rockefeller and others. It continues to improve science teaching at all levels by developing new curricula and new

learning materials, and is one of the most active centres in this field in Latin America.

Another case worth mentioning is that of Venezuela. At the request of the government, Unesco sent two science education specialists to Venezuela in 1971 to work for a month, with the Ministry of Education and the National Council for Scientific and Technological Research (CONICIT), on plans for establishing a national centre for the improvement of science education, the Centro Nacional para el Mejoramiento de la Enseñanza de la Ciencia (CENAMEC). The centre was officially created by the government in 1974 and it started operating in 1975, under the joint auspices of the Ministry of Education and CONICIT.

Some other centres

Very brief mention of a few other centres follows. The list is not complete and should be considered simply as representative. Page numbers in parentheses refer to the *Eighth Report of the International Clearinghouse on Science and Mathematics Curricular Developments, 1972* [24].

Philippines—Science Education Centre, University of the Philippines (p. 119). A centre for curriculum development, teacher education, research in mathematics and science education. Founded 1964. Supported by: The Ford Foundation; Unicef; National Science Development Board and the University of the Philippines.

India—Vikram A. Sarabhai Community Science Centre (p. 68). Founded 1963. Funded by the Government of India, the State Government of Gujarat and the Nehru Foundation for Development. Laboratories, library and workshops devoted to development of materials for science teaching improvement at all levels.

Costa Rica—Center for the Preparation of Teaching Materials for Science Instruction. Founded in 1968. Funded by several governments in Central America.

Japan—Institute for Educational Research, Tokyo.

Lebanon—Science and Mathematics Centre, Beirut.

Chile—Centro de Perfeccionamiento, Experimentación e Investigaciones Pedagogicas (CPEIP) (p.398) . One of its projects is a self-instructional in-service training project (PPS) for teachers of science using independent study, laboratory investigations and discussions.

6

Examples of science teaching activities in areas of high priority

In this chapter some examples of projects exemplifying innovation and improvement in the teaching of science world-wide will be given. We have already indicated that over 200 projects are summarized in the eighth report of the international clearinghouse [24]. Only a few of these can be mentioned so we must indicate what criteria were used to choose them.

First, we selected areas of activity which were felt to be of special importance and merited priority action. These include integrated science, teacher education, educational technology, evaluation, design and production of materials, the role of experiments and the learning process in children.

We further limited our choices by giving preference to primary and secondary levels. Tertiary education (post-secondary education in colleges and universities) is not completely omitted but, for the most part, we limit ourselves to the education of science teachers as an example of tertiary level activity. Finally, preference has been given to projects that take place in developing countries or to those whose objectives include the solution of problems of relevance to them.

Inevitably some readers will be disappointed not to find their favourite project discussed here. We simply had to limit the number of examples. We hope that the ones we have chosen will motivate readers to look more deeply into the other projects listed in the clearinghouse report and elsewhere.

Integrated science

Since we have already discussed the characteristics of integrated, co-ordinated and multidisciplinary activities we will here use the term 'integrated' somewhat generally to refer to all courses in which, to

quote once again from the Unesco co-ordination meeting (see page 118),

> the principles of science are presented so as to express the fundamental unity of scientific thought and to avoid premature or undue stress on the distinctions between the various scientific fields.

Although the clearinghouse report [24] contains summaries of sixty-five integrated science projects in the United States and a total of thirty-one in other countries we have chosen only one project in the United States and seven others, five of them in developing countries. In choosing them I have leaned heavily on Unesco's *New Trends in Integrated Science Teaching,* Volumes I-III [53], on the eighth clearinghouse report [24] and on discussions with Unesco project officers who supplied me generously with relevant literature and considered opinions.

The geographical regions I have chosen are Asia, Africa, Latin America, the Caribbean, Oceania, Europe and North America. The page numbers refer to the relevant section in the eighth clearinghouse report.

Asia

Only two of the twenty-two Asian projects listed in the clearinghouse report have the word 'integrated' in their titles (although others may also deal with integrated science). One is in Japan (p. 82) and one in Malaysia (p. 87). I shall describe the latter.

For further information on integrated science activities in Asia the reader is referred to the Unesco report of a 1970 regional workshop held in Bangkok—Integrated Science Teaching in the Asian Region—and the report of the Unesco-RECSAM workshop on the teaching of integrated science in Asia held in Penang (Malaysia) in 1972.

The project on 'Integrated science (lower secondary)' (p. 87) has its headquarters in Kuala Lumpur (West Malaysia). It is supported by the Ministry of Education of Malaysia and is associated with the Centre for Educational Development Overseas (CEDO) of the United Kingdom.

It started in 1968 with the over-all objective of improving science education in the lower secondary schools (junior high) of Malaysia by reorienting the teachers, modifying the Scottish Integrated Scheme to suit Malaysia and developing relevant materials such as teacher's guides and prototype apparatus.

It has produced a course in which physics, chemistry and biology are integrated. Both teachers and students learn by working in the laboratory. The teachers are required to work through most of the pupil experiments and to improvise some apparatus.

Another feature is that programmed instruction and audio-tutorial methods are used.

The materials include a syllabus, pupil work sheets, an apparatus list, a newsletter, textbooks, teachers' guides and test items. They were originally written in English and have been or will be translated into Malaysian for use in Malaysia and western Africa. So far, about 750 schools and 2,000 teachers are using some of the materials with 465,000 students. About 400 schools and 1,100 teachers are currently using the entire programme with 150,000 students.

Plans for the future include progressive implementation in pilot schools, writing a teachers' guide to the worksheets and developing new prototype apparatus and audio-visual materials.

Africa

There are at least four African integrated science projects among the total of sixteen listed in the clearinghouse report. One is the Science Education Programme for Africa (SEPA) (p. 45) and another is the African Primary Science Programme (APSP) (p. 29). These two projects are related. Unesco has published a report of a regional workshop for science education planners entitled 'Planning for Integrated Science Education in Africa' held in Ibadan (Nigeria) in 1971.

I have chosen the African Primary Science Programme as an example because it is in the modern idiom as far as content and approaches are concerned but geared to the realities of developing countries. It is highly imaginative, flexible and relatively easy to teach. It was developed for children in simple village schools—from kindergarden to Grade VIII. It has received assistance from USAID and the Ford Foundation and is associated with the Education Development Center of Newton, Massachusetts.

The over-all purpose of the project is to introduce modern methods and materials for teaching science to primary schools of English-speaking tropical Africa. Its specific objectives are:

1. To develop a range of materials using the local environment and covering a wide diversity of science topics.
2. To assist with the establishment of a network of locally manned and controlled science centres where continuing development can take place.
3. To encourage the formation of an African organization able to carry on assistance to interested countries in science education and to conduct various international activities in that area.

Although it is not called an integrated science programme, a glance at the titles of some of the materials produced suggests that they do indeed 'avoid premature or undue stress on the distinctions between the various scientific fields'.

Some of the titles of activities for the lower primary grades, for example, are: Arts and crafts; Cooking; Construction; Dry sand; Wet sand; Exploring the local community; Exploring nature; Plants in the classroom; Playground equipment; Water; Woodwork. There is a pupils' book on *Making a Magnifier*. Teachers' guide titles include: *Ask the Ant Lion; Birds and Twigs; Construction with Grass; Chicks in the Classroom; Measuring Time; Mosquitoes; Small Animals; Torch Batteries and Bulbs.*

At a higher level there is a pupils' book called *Making a Microscope*. Teachers' guide titles here include: *Sinking and Floating; Seeds; Changing Solids—Soldering; Scientific Look at Soil; Balancing and Weighing; Pendulums; Liquids; Sound: A Look at Musical Instruments; Friction; Wheels.*

Other aids include four films and a 'Science Library' series.

This project was started through the efforts of Professor Jerrold R. Zacharias of the Physics Department of the Massachusetts Institute of Technology. A planning conference was held in Kano (Nigeria) in 1965 and developed into a programme involving fourteen countries of English-speaking tropical Africa. The materials have been used in Liberia, Sierra Leone, Ghana, Nigeria, Ethiopia, Kenya, Uganda, the United Republic of Tanzania, Malawi, Zambia, Lesotho, Swaziland, Botswana and Gambia.

APSP has helped to establish science centres in Ghana, Kenya, Nigeria, Sierra Leone, the United Republic of Tanzania and Uganda.

The main method of instruction promoted has been independent study, laboratory investigations, discussion sessions, field experiences and small group projects. Materials were originally written in English. A Swahili translation was undertaken by the Tanzanian Government.

As in all of these projects teacher preparation is important and has been one of the main tasks of the science centres. Seminars and workshops are conducted periodically in most programme countries to work with new materials and in general to acquaint tutors, teachers and ministry of education officials with new science teaching methods.

We do not have space to discuss in similar detail the project which began as an African continuation of APSP but it is significant that it came into being. It is called the Science Education Programme for Africa (SEPA) and is discussed in the clearinghouse report (p. 45). Up-to-date information can be obtained from the Project Director, SEPA, Box M188, Accra (Ghana).

Caribbean area

Of the four Caribbean projects listed in the clearinghouse report, two are integrated science projects. One is the West Indies Science Education Project and the other the West Indian Science Curriculum Innovation Project (WISCIP). I shall describe the latter as an example of

a project which is perhaps slightly more conventional than some of the others but, nevertheless, appropriate to the realities of the Caribbean.

WISCIP (p. 187) is an integrated science curriculum stressing an ecological approach which was developed in Trinidad starting in 1968. It received support from the Centre for Educational Development Overseas (CEDO) in London and is associated with the University of West Indies Institute of Education.

Its principal objective is to introduce modern discovery-based science teaching methods in English-speaking Caribbean Junior Secondary Schools specifically by (a) preparing teachers' guides and visual aids for the course; (b) piloting innovations in science education; (c) training non-graduate teachers involved in the project; (d) developing an ecological approach to biology teaching involving pupils at all stages of the course.

It is an integrated science project for pupils in the 11–14 years age range in all ability groups within the junior secondary schools.

A unique characteristic of the project is that it has faced squarely the problem of inexperienced staff. Every lesson is written out in detail for a three-year course designed for teachers with very meagre qualifications who often have to work in ill-equipped science rooms. Their brochure says:

> We claim the indulgence of experienced teachers who may use our materials for much advice which is, in their case, unnecessary, but which may stand a new member of the profession in good stead.

The materials have been used in British Honduras, Cayman Islands, Turks Islands, Caicos Islands, British Virgin Islands, St Kitts-Nevis and Anguilla, Antigua, Dominica, St Lucia, St Vincent, Grenada, Barbados, Trinidad and Tobago, and Guyana.

The total number of those who use any of the materials amounts to 100 teachers, 15,000 students and 75 schools. In almost all cases they use the entire programme.

A two-week induction course is held for all teachers. This is supplemented by one-day briefings twice a term. A pair of consultants visit schools and brief teachers in each territory two to six times per year.

Australian area

Of the twelve Australian area projects listed in the clearinghouse report, at least two involve integrated science teaching. One is called the Science Foundation for Physics Integrated and Co-ordinated Science Textbook Project for the New South Wales Six-year Science Courses (p. 159) and the other is the Australian Science Education

Project (ASEP) (p. 128). The first was a pioneering project that started in 1962 and bears the indelible stamp of Professor Harry Messel. It has received wide publicity. The second project did not get started until 1969. It includes some significant innovations and will be described here.

The distinguishing features of this Australian project, ASEP, are that it is modular and hence flexible and that it stresses an environmental approach. Because of the growing importance of, and interest in, the environment, its curriculum will probably be of special interest to several international groups at present preparing to stress environmental studies in education.

It is funded by the governments of the Commonwealth and six states of Australia. It evolved from the Junior Secondary Science Project and was initiated in 1969 in Hawthorne, Victoria (Australia).

The over-all purpose of the project is (a) to design science experiences which contribute to the development of children, and (b) to develop instructional materials in science for use by teachers in Grades VII to X in secondary schools throughout Australia.

Specifically, it aims to develop some understanding of man, his physical and biological environment, and his interpersonal relationships; skills and attitudes important for scientific investigation; some understanding of the nature, scope and limitations of science; some understanding of the consequences of science and technology.

In amplification of these objectives two further statements are made by its directors:

> The kind of understanding at which the Project aims enables the children to operate more effectively in their environment.
>
> To arouse and foster the interest of children is of prime importance in the development of understanding, skills and attitudes.

The characteristics of the project include (a) the development of materials designed to permit individual students' progress by providing choice within topics to the students and the teachers, and (b) a scheme which forms the basis for a choice of topics emphasizing the environment as seen by children and extending beyond traditional subject matter. It is designed for Grades VII to X or VIII to X as appropriate in the secondary schools of Australia. Most of the students are in the 11–16 year range.

The materials produced will include approximately forty units, each of which includes student material booklets, student record booklets, student service booklets, a teachers' guide, slide sets and tapes. The booklets are printed inexpensively but use colour plates in situations where colour is pedagogically functional.

In 1971–72 when the project was still incomplete, about 109 teachers were using the materials in the same number of schools with 4,360 students.

Considerable emphasis is given to pre-service and in-service teacher preparation for the project.

The project was not funded for an extensive evaluation effort of the final products, or for basic research relating to instruction, but it is actively encouraging outside organizations to conduct such studies with the hope of supplementing the contribution of ASEP's own evaluation group.

United Kingdom

Thirty-seven projects are listed for the United Kingdom in the clearinghouse report. Only one, the Schools Council Integrated Science Project (SCISP): 'Patterns' (p. 247), has 'integrated science' in its title but several other projects, notably the Scottish Secondary Science Schemes (p. 286) and some of the Nuffield Projects (p. 216–38), are oriented towards interdisciplinarity. I have chosen SCISP as an example.

SCISP is one of the most innovative of all existing projects, bringing in elements of sociology and social sciences as well as the physical sciences. It is a project of the Schools Council of the Northern Ireland Ministry of Education. It originated in September 1969 at Chelsea College, the Centre for Science Education in London.

Its over-all purpose is to provide a broad integrated course in science for the academically more able 13–16-year-old pupils with an emphasis on the social implications of science. It is intended to consume no more than one-fifth of the school timetable.

The integrating themes throughout the scheme are 'pattern searching', and 'pattern using to solve problems'. A pattern is defined as a generalization or an explanation. There is a hierarchical learning structure based on the sequence: recall—concept learning—pattern finding—problem solving. Students' thinking is based on three fundamental concepts: building blocks, energy and interactions. The content includes social science, earth science, physical science and biological science. It is aimed at 13–16-year-old students leading to a double certification General Certificate of Education—Ordinary level (GCE O-level).

I shall give the specific objectives in greater than normal detail. They include:

Knowledge: (a) to recall and to understand that information which would enable pupils to take Advanced (A) level courses in biology, physics, chemistry or physical science, to follow a job in science and technology, to read popular scientific reporting and to pursue science as a hobby; (b) to understand the importance of patterns in solving problems (both of a laboratory and of a household type); (c) to be able to recognize scientific problems; (d) to understand the relationship of science to technical, social

and economic development, and to appreciate the limitations of science.

Attitudes: (a) to be faithful in reporting scientific work; (b) to be concerned for the application of scientific knowledge within the community; (c) to have an interest in science and technology and a willingness to pursue this interest; (d) to be willing to make some decisions on the balance of probability; (e) to be willing to search for patterns, to test for patterns, and to use the patterns in problem solving; (f) to be sceptical about suggested patterns.

Skills: (a) to work independently and to work as part of a group; (b) to discover and to use available resources such as books, apparatus and materials; (c) to organize and to formulate ideas in order to communicate to others, and as an aid to understanding, critical analysis, etc.

In 1972 about seventy-five teachers were using the entire programme in thirty schools with 2,000 students in Northern Ireland, Birmingham and London.

Materials produced include a teachers' handbook and guide, pupils' manual and books and a technicians' manual, radio programmes, filmstrips and films.

Adequate provision has been made for pre-service and in-service teacher training.

A more complete description of the project appears in W. C. Hall, 'Case Study in Curriculum Decision Making' [58].

United States

There are 121 United States projects listed in the clearinghouse report. Of these, sixty-five are listed as integrated projects. It is patently impossible to describe the whole movement by choosing one example. I have chosen the Science Curriculum Improvement Study Project (SCIS) (p. 796)—which, incidentally, is not listed under 'integrated science' but under 'elementary science'—not because it is typical but because it is widely used, interesting and important. I am also probably biased in its favour because the Lawrence Hall of Science, its host institution, has collaborated with Unesco in an internship programme for science educators for developing countries.

The 1974 brochure of the Lawrence Hall of Science says the following about SCIS:

> Over the last five years at the Lawrence Hall, an ungraded, sequential physical and life science curriculum has been developed that enables teachers to turn their classrooms into laboratories where students can explore materials, investigate the properties of these materials, and evaluate their findings. The SCIS teacher observes the students in their

investigations and leads them to see the relationship of their findings to key scientific concepts.

Based upon current theories of how children learn, and developed and tested extensively in urban, suburban, and rural schools, the SCIS project is now focused on providing evaluation supplements for teachers' use in identifying pupils' progress. This final year (1975) of funding from the National Science Foundation will complete the cycles of research, development, implementation, and evaluation. Current annual expenditures are approximately $500,000.

SCIS is funded by the National Science Foundation through the University of California, Berkeley.

The objective of SCIS is the development of scientific literacy based upon a sufficient knowledge and understanding of the fundamental concepts of biological and physical sciences for effective participation in twentieth century life, the development of a free and inquisitive attitude and the use of rational procedures for decision making.

It is designed for elementary school children from kindergarden to Grade VI. It has been used successfully with inner-city and rural children and has been adapted for use with blind children.

SCIS uses a materials-centred approach in which the elementary classroom actually becomes a laboratory. The children learn through direct physical contact with natural phenomena and other experiences.

The titles of the units used in years 1–6 are:

1. Material objects and organisms.
2. Interaction, systems and life cycles.
3. Subsystems and variables.
4. Relative position and motion.
5. Energy sources and communities.
6. Ecosystems and models.

The materials produced by SCIS are being used by schools in practically every part of the United States. It is estimated that the number of children using SCIS, based on kit sales of preliminary and final editions is approximately 800,000 (1972).

An extensive programme of teacher preparation is an integral part of SCIS.

The improvement of teacher education

Although new ways of learning are being tried, including self-instructional techniques to be discussed in the section on educational technology, it seems safe to say that for the foreseeable future teachers will be required in the educational process. A mass shift to schools without teachers seems extremely unlikely.

What does seem very likely, however, is that teachers will play new but extremely important roles. In all the projects for science teaching improvement that we know of there has been a definite shift away from the old concept of the authoritarian teacher who supposedly is the fountainhead of knowledge and a strict disciplinarian to the new concept of the teacher as 'learning facilitator' (an unfortunate term for an important idea).

With the shift in emphasis from teaching to learning, the teacher should play the role of stimulator, motivator and helper rather than that of dispenser of knowledge, especially in flexible programmes geared to the differing needs of students with different abilities and backgrounds. The teacher just cannot know everything but he (or in many cases she) must know how to lead the student, guided by a curiosity which has been imparted to him by the teacher through example, to find out for himself.

Almost all science teaching improvement projects, starting back in the days of PSSC and including the 200 or more existing projects world-wide have a teacher preparation component. When that was initially neglected, as it may have been by over zealous pioneers who felt that first and foremost the content or subject matter had to be chosen carefully and then presented properly through teaching aids, it was very soon realized that curriculum reform could get nowhere without teachers capable of, and interested in, handling the new content and methodology. There is no need to document this here. The reader is, once again, referred to the clearinghouse report [24] where the activities of curriculum reform and course content improvement projects are given in detail. It will be seen that practically all of them include activities for upgrading of teachers.

It is worthy of note that the term 'teacher education' seems to be replacing 'teacher training' and rightly so, because the transformation of the older teacher or the proper development of the new teacher demands activities that transcend the usual meaning of 'training'. The reader will have to forgive me, however, if occasionally I lapse back into the more alliterative 'teacher training'.

What is new about the new courses that puts new demands on teacher education? First, the content is new. That was the first thing that the reformers changed—they had seen outmoded content in the

old books. Next, the approaches to teaching are new. These come under headings like 'inquiry', 'process', 'relevance' and 'integrated science'. Another difference—related to the relevance approach—is the emphasis on societal concerns. There are also now more options for both the teacher and the student. These are based on the fact that there are individual differences among students and among teachers as well. There are new techniques like team teaching. There are new learning aids like film loops, cassette television and computers. There is a growing recognition of the importance of psychological and social factors in learning. It is clear, therefore, that many new responsibilities are being placed on the teacher's shoulders. He/she needs help in learning how to cope with them.

Now, is there anything in the system that has not changed? I believe the important factor that has not changed is that teachers and students are human beings and no new approach, method, teaching material or technique is going to be very useful in the teaching-learning process unless we give high consideration to the importance of the human role of the teacher as an understanding, sympathetic individual who has a concern for the human development of his/her pupils. No computer-assisted programme that I know of can replace the teacher as a stimulator, motivator, guide, helper and a rewarder of student activity.

It has been said that what is most worth learning is the knack of learning itself and this applies to teachers as well as to students. The teacher teaches as he/she was taught, we are told. If that is the case, all pre-service and in-service teacher education has to be modified so that it exemplifies the new ways in which we want future teachers to act.

Examples of teacher education projects

Whenever a reform project is started teachers are needed to implement it. It is for this reason that attention is usually given first to in-service training. This usually means that some existing teachers have to be trained in the new ways of teaching. The usual procedure has been to provide in-service teacher training courses for them.

As time goes on and some of the improvements tend to become more or less permanent fixtures, it becomes necessary to adjust the pre-service education of teachers to conform with the new standards.

Eventually, because it is realized that continuous change is inevitable both in content and methodology, programmes of in-service and pre-service education need to be carried out simultaneously.

When we use the term 'teacher' we may have in mind either the primary school teacher, the secondary school teacher or the teacher of teachers (who often works at a university or teacher training college).

Of the many teacher education projects that exist I have chosen

three. All are in developing regions of the world. All have tackled the teacher education job with imagination and vigour. One (Chile) stresses in-service education through the novel means of correspondence and self-instructional techniques. Another (Philippines) does a particularly good job with pre-service education and the third (Papua New Guinea), a special case, was chosen to illustrate how dedicated, sometimes little-known men are sent out by Unesco to tackle a situation that would seem nearly hopeless by ordinary standards in advanced countries and manage to do a constructive job in the short period of three years. The numbers in parentheses refer, once again, to pages in the eighth clearinghouse report [24].

Proyecto de Perfeccionamiento en Servicio (PPS) (p. 398)

This Chilean project with headquarters at the Centro de Perfeccionamiento, Experimentación e Investigaciones Pedagogicas (CPEIP) in Santiago is basically an in-service teacher training project for teachers working in Grades V to VIII inclusive. A unique feature is that it is a correspondence course which reaches teachers even in remote areas.

What the teacher finally does in the classroom is of great concern to PPS. Because it is an in-service course, the teachers keep working with their students during the course.

Teachers participating in the course are organized into local groups. This helps them to solve specific teaching problems by themselves and reduces the need for supervision by PPS personnel. Evaluation of the course is done by assessing the teacher's responses to questions in the correspondence course and by observing what he and/or his students do in the classroom.

The objective of PPS is to develop a self-instructional in-service training programme for teachers with the following characteristics: (a) it must be capable of reaching any teacher in the country; (b) it must not take the teacher away from his pupils during the course; (c) the teacher's classroom activities are an integral part of the programme.

To carry out the programme the teacher is supplied with the following materials: (a) self-instructional materials designed to develop in the teacher the basic skills of the scientific processes; (b) analysis of, and commentaries on, the hierarchical development of skills in each process and on ways to evaluate the student's progress in developing process skills; (c) self-instructional material to insure that the teacher will be adequately prepared before initiating a given learning situation with his students; (d) teaching guides for each learning situation, each guide containing the objectives of the learning situation specified in terms of terminal student behaviour, the relationship between the objectives and the hierarchical levels of the scientific process in which skills are being developed, the rationale of the teaching situation with its scientific and pedagogical implications, suggestions

for activities to be carried out in the classroom, and, finally, evaluation instruments to be used during or after each activity; (e) evaluation materials, for the teacher to test his own progress and to use with his students.

If we include those who use any of the materials at all, there were in 1970 about 5,000 teachers, 400,000 students and 4,000 schools. If we count only those who have adopted the entire programme, there were about 1,200 teachers, 80,000 students and 1,000 schools.

Plans for the future (in 1970) included a parallel programme from kindergarden to Grade IV with special emphasis on integrating science curriculum with relevant community problems at the local and national levels, as well as using local scientific, technological and production agencies for science curriculum improvement.

It is interesting, perhaps, to note in passing that Hector Muñoz, one of the principal originators of PPS, was one of the very active participants in the Unesco Physics Pilot Project held in 1963 in Brazil. Muñoz writes [59]: 'The emphasis is on *activities* designed to develop the student's basic skills in the fundamental processes that comprise the act of doing science.'

Science Education Centre,
University of the Philippines (p. 119)

This centre was initiated in 1964 with the support of the Ford Foundation, Unicef, and the Science Development Board of the University of the Philippines. The centre has worked in collaboration with the Department of Education of the university.

In its initial phase the centre focused its activities on curriculum development but later a second phase was started with the improvement of science teacher education as its main concern. Hence innovative approaches are being tried out not only on the elementary and secondary levels but also on the teacher-education level.

The objectives of the centre are: (a) to develop curriculum materials for elementary and secondary school mathematics and science (student texts, teachers' guides and laboratory manuals) which emphasize inquiry and promote skills for independent learning rather than dogmatic assertion and memorization of facts; (b) to improve science teacher education; and (c) to carry out research in mathematics and science education.

I will emphasize teacher education in what follows but it cannot be discussed adequately without considering the over-all programme of the centre.

Some of the unique characteristics of the project are that, unlike certain other local activities with similar purposes, it has full-time staff for this work, that programmed instruction is being utilized and that intensive evaluation of tryout programmes is being conducted.

The work of the project also depends upon the more conventional methods of instruction including lectures, seminars, discussion sessions and laboratory investigations.

Activities conducted for pre-service and in-service teacher training include summer institutes to orient prospective teachers to the materials they will try out.

These institutes are financed by the National Science Development Board of the university. The approximate cost is 350 Philippine pesos per participant per summer. There is a graduate programme in science education leading to the degree of master of arts in teaching.

As a consultant service available for teachers using the materials there are monthly meetings of teachers with the staff of the Science Education Centre.

Teachers' guides, pre-tests, post-tests and some teaching devices designed especially for elementary teachers are examples of the materials available for science educators to use in preparing teachers in pre-service and in-service courses.

Besides the pupils' and teachers' guides for elementary school science and mathematics and high school texts and laboratory manuals in the basic sciences, the materials that have been produced include a programmed unit for teachers entitled *The Gene* and a sourcebook for teachers entitled *Plants of the Philippines*. Each course that is developed undergoes a two-year period of trial use in from six to ten schools after which revision is carried out on the basis of feedback information from students and teachers, tests and the judgement of the work groups.

The centre has a full-time academic staff of six senior members and fifteen research assistants. In addition, a number of teachers and professors from the University of the Philippines or other universities work part time in the various activities in the basic sciences and mathematics. These part-time workers are chiefly writers and reviewers of manuscripts. The senior staff constitutes the Department of Science Teaching in the College of Education.

A unique teacher educational activity is its scholarship programme, funded by Unicef and the National Science Development Board, which brings to the centre each year forty teacher educators from thirteen leading teacher education institutions selected from all over the country. These teacher educators are on an 18-month programme which, besides upgrading the subject area background of the participants, is designed to expose them to new developments in science education, new curricula, new approaches to teaching and new techniques in evaluation and in education—particularly in the training of teachers. This is the programme that leads to a master of arts in teaching (MAT) degree.

When the teacher educators complete their training programme they take to their institutions the basic equipment that they will need to conduct training programmes for teachers.

Another development is that five out of the thirteen institutions participating in the MAT scholarship programme were designated Regional Science Teaching Centres. The work of these regional centres is well co-ordinated with that of the Science Education Centre.

Unesco Papua New Guinea project

One of the most interesting features of this project is that it shows the stimulating effect that Unesco can have in a region of the world that is both geographically isolated and economically depressed —Papua New Guinea. It is also one of the least densely populated countries of the world (three people per square kilometre) with a total area of 806,000 square kilometres.

Science teaching improvement activities began as early as 1965 but I shall describe only a project on curriculum development and teacher training conducted by a consultant sent by Unesco during February 1968 to December 1971 to assist in the development of a primary science course in which a set of activity cards and a kit of simple equipment for the teacher and the pupils played an important role.

The objective was to prepare teachers to teach a modern, activity-based primary science course. This was a formidable task because about half of the teaching force had themselves only received primary education followed by a one-year course in teacher training. Their science background was practically non-existent. They had been recruited and trained in the early days of the educational system and would eventually be phased out either by retirement or retraining. The other half of the teachers had received two years of high school education followed by two years of teacher training. Very few had studied science in college and their two years of science in the high school would have included little if any experimental activity.

The primary science course envisaged was to consist of activities carried out by the children themselves using simple materials under the supervision of the teachers. It was intended that the children should learn to discuss their activities; to ask questions; to challenge explanations and, if possible, to investigate further.

This course represented such a departure from the usual approach that it was felt it would be beyond the capabilities of the first group of teachers—those who themselves had had only a primary education—and that it would be difficult even for teachers in the second group—those whose two years of high school science had not included experimental activity. Consequently, it was decided that the first group should not be expected to teach the new primary science course and that those in the second group would be required to attend a five-week in-service course during the vacation period. This course was designed to (a) enhance the science background of the teacher; (b) develop appropriate classroom skills; (c) familiarize the teacher

with the use of simple equipment; all in relation to the specific activity lessons of the new course. In addition, appropriate science courses would be developed in the teacher training college so that a supply of pre-trained teachers would be forthcoming.

Space does not permit a detailed description of the progress of this experiment. The interested reader is referred to reports of the International Clearinghouse on Science and Mathematics Curricular Developments which preceded the eighth report of 1972 [24].

What I found most instructive was a booklet which described the simple Pilot Project Cards which teachers and students used to guide their activities.[1]

A feature of the project that is worth mentioning is that kits supplied by Unesco and Unicef played an important role in the project. Unicef has produced (with the assistance of Unesco) a guide-list of science teaching equipment [60] and a book of illustrations of science teaching apparatus and equipment available from Unicef [61] which the interested reader may obtain from Unicef headquarters in New York.

Although I have not given details of how the course progressed I will quote the following from a communication received from the Unesco consultant:

The over-all staffing for the first years of the project was:

	Schools introduced	Teachers in-service trained	Teachers pre-service trained
1969	40	40	nil
1970	320	170	150
1971	300	100	400
1972	200	nil	600

By 1971, the number of science teachers trained was considerably more than the number of schools involved, and it was possible to terminate the programme of five-week courses.

Guidelines and trends in science teacher education

The involvement of teachers in the design of curricula and materials

One aspect of teacher training which we have not had space to cover is the involvement of teachers in the process of designing new curricula

1. It seems to have been locally printed (Papua New Guinea Primary Science Project, Pilot Project Cards, PMTC 1968–1969) and copies of it may still be available from the Director of Education, Education Department Headquarters, Konedobu (Papua New Guinea).

and new materials for science teaching. This idea has been elaborated by N. Joel [62] and will be discussed below under the heading 'The Design and Production of Materials and Equipment for Science Education'.

Two other useful references, published by the American Association for the Advancement of Science, are: *Pre-service Science Education of Elementary School Teachers. Guidelines, Standards and Recommendations for Research and Development* (Miscellaneous Publication 70-5) and *Guidelines and Standards for the Education of Secondary School Teachers of Science and Mathematics* (Miscellaneous Publication 71-9).

The role of science teacher associations

One of the most encouraging movements for science teaching improvement is that toward the formation of associations of science teachers for the purpose of exchange of information, improving ways of teaching science, mutual encouragement and intellectual stimulation.

Both Unesco and ICSU have been instrumental in the creation of an organization that should help in this movement. It is the International Council of Associations for Science Educations (ICASE).[1]

The purpose of this organization is to further the work of associations throughout the world which are concerned with the promotion of science education by (a) acting as a clearinghouse for information about its members; (b) publishing a periodical letter or newsletter; (c) organizing international conferences in association with other bodies (e.g. Unesco, ICSU); and (d) promoting exchanges of science teaching personnel.

It held its foundation meeting at the University of Maryland in 1973, has prepared a Directory of Science Teachers Associations and appointed an Editor of Publications.

There are twenty national science teachers associations (foundation members) along with seven organizations such as CEDO and Unesco.

1. Inquiries should be addressed to Mr D. G. Chisman, Executive Secretary, The British Council, 10 Spring Gardens, London SW1A 2BN (United Kingdom). The French title is Federation Internationale des Associations de Professeurs des Sciences (FIAPS). A brochure, a report of the foundation meeting and a newsletter are available.

Educational technology

Educational technology has grown so rapidly in volume and importance in recent years that a whole book could be devoted to it. In order to say something meaningful about it in a small space I have decided to limit myself to four topics: What is it? How did it get started? What are some of the basic ideas behind it? How is it applied to the improvement of science education?

Fortunately Unesco held a meeting of experts dealing with the subject in September of 1972. They appear in a volume entitled *New Trends in the Utilization of Educational Technology for Science Education* [63] and I will lean heavily on the state-of-the-art papers written by the experts for this meeting.

What is it?

A universal educational goal seems to be better learning for more people. How is this to be achieved? It is obvious that the educational system, whose inputs are teachers and materials and whose outputs are graduates with a growing diversification of skills and knowledge, must be made more efficient.

The term 'efficiency' smacks of machines and technology. It sounds too mechanistic to be applied to the human task called education. But we will have to get used to the fact that unless we can measure the effectiveness of the teaching process we will never know whether or not we have improved it.

This concern for attaching a measure of effectiveness to an operation is reminiscent of operations research and systems analysis and indeed some of the methods of these disciplines are being applied to education under the name of educational technology (see Chapter 5 under 'The Trend towards a Systems Approach to Education').

As we increasingly recognize that it is learning on the part of the student which should be the indicator of success in the educational task, it becomes clear that new teaching-learning strategies which permit quantitative assessment of achievement need to be developed.

The combination of approaches, methods and materials used to achieve learning is called educational technology. This does not mean simply the totality of technical aids such as films, teaching machines and computers used in education; they are simply examples of technology in or for education. What we have in mind is a technology of education; that is, a method or approach combined with the necessary materials to bring about improved learning.

The old approach—or old educational technology if you like—was based on assumptions which are no longer tenable. It assumed that

the teacher's main task was to transmit information. The hardware of the old technology includes the textbook, the chalkboard and the chalk, the student's notebook and pencil and, occasionally in primary grades, the teacher's ruler or whip. If the student did not learn, it was assumed, unfortunately, that it was his own fault. It was seldom suggested that the teacher or the system was at fault.

In modern educational technology the most important consideration is not that the hardware include such things as television sets, projectors for film and slides, cassette tape recorders for sight and sound and self-instructional booklets—they are indeed examples of the new technology in education. The important consideration is that we now recognize that the ultimate objective is learning on the part of the student.

The term educational technology is now almost synonymous with the use of a systems approach. It implies a systematic development of teaching-learning strategies which have the following in common:

1. They begin by stating in advance what the student should be able to do at the end that he was not able to do at the start. In other words you must state your behavioural objectives in advance.
2. They utilize all the known facts of learning theory and a combination of methods, techniques and materials chosen to maximize the probability that the student will learn—the proof of learning being the ability of the student to do what was intended.
3. They culminate in an assessment which measures the success of the projection in terms of how well the student achieves what the planner said he would achieve.

Today an impressive array of hardware with its corresponding software exists to assist us in the teaching-learning process. There is a natural tendency to think that modern education technology consists solely of the new teaching-learning aids such as computers, programmed learning materials, film, loops, experimental kits, radio and television. If, however, we consider education from a systems point of view we realize that the aids we have named are just the means whereby we get only a small part of the educational task performed.

I repeat for emphasis, then, that hardware and software used in teaching do form part of the technology of education. But it would be a mistake to treat the things of learning as if they constituted the whole of what we now call educational technology.

How did it get started?

Instead of writing a precise history of the subject, which would be interesting but which I am not prepared to do, I will relate the sequence of events as I remember them from my involvement in

different science teaching improvement projects. The reader will recognize gaps and possibly even errors in this synoptic review and I hope that my treatment motivates someone to do the scholarly job that still needs to be done.

In the nineteen-fifties, when the science curriculum reform movement mentioned in Chapter 4 first started, word of teaching machines began to get around. To many of us who were physicists working in course-content improvement projects, with meagre backgrounds in psychology and educational philosophy, the idea seemed fascinating. It became conceivable to me that one could arrange a sequence of graded questions which, when answered correctly by the student, could lead him on to learn the simple facts of, say, the reflection and refraction of light, but I rebelled against the thought that such a mechanistic approach to learning could ever replace me as a teacher. I felt I could motivate a student to learn and be enthusiastic about what he had learned and that a machine could not. I tended to think of the teaching machine as a toy; expensive, novel and glamorous but not to be taken seriously in the educational process.

But as I thought more about the 'software' or the programme that had to go into such a machine rather than the 'hardware', which in this case was the machine itself, I began to realize that anyone who wrote a good programme had to first understand the subject matter thoroughly and secondly arrange the questions in the proper logical sequence. The increment in knowledge between one step and the next would have to be small enough to be easily grasped and large enough to keep the process from being tedious and boring. I began to admit to myself that the writing of a good programme would, at least, be a good exercise in the teacher training process even if all the evidence was not in as far as its effectiveness in the learning process was concerned.

For this reason, when I assumed responsibility for Unesco's first pilot project for the improvement of physics teaching in Latin America, I proposed that we include the writing of programmed instruction sequences as part of the teacher training programme.

By 1963 it had become apparent to many of us that the expensive teaching machine could be dispensed with, because the important thing was the programme which could be presented as a series of frames on cards or even printed in book form.

What had survived was the basic idea that to write a good programme you had to state your objectives for the learning sequence in a behavioural way. That is, once again, you had to specify what you wanted the student to be able to do at the end of the sequence that he was not able to do at the start. And to do that you had to begin with a very thorough knowledge of subject matter.

We could not have expressed our thoughts then in the language of B. F. Skinner's 'operant conditioning' but we had obviously been

convinced of the validity—within certain limits—of the idea that it is possible to modify some of the student's behaviour patterns by the techniques of programmed instruction. The participants in the Unesco pilot project in Brazil were writing, in 1963, what were probably the first programmed-learning sequences in Latin America. Some of the participants in that project have become the prime exponents of educational technology and science education reform in Latin America.

This very narrowly focused look at the early days of programmed learning, concentrating on personal experiences, has, I believe, some general validity because we have since learned that at about the same time groups in other parts of the world, many of them in the United States but some in the U.S.S.R. as well, were experimenting with programmed learning (we began making the switch from 'instruction' to 'learning' about that time) and having more or less parallel experiences.

They found, for example, that many different ways of presenting the sequence of frames were possible; that they did not require a costly machine; that a straightforward linear sequence might become boring and tedious; that it was often very difficult to write behavioural objectives and harder still to go through the ideal procedure of testing each frame on potential students in order to get corrective feedback.

Commercial companies began producing programmed-learning texts and some of these were so poor—for lack of validation in actual use—that they began to produce a negative reaction among teachers and students.

Nevertheless, the experiments did reinforce the idea that once you had stated your objectives in operational terms you saw clearly what the student would be required to do to prove that he had learned, and that alone motivated the introduction of other experiences and materials into the learning process.

In summary, then, I believe that the concepts of modern educational technology have grown out of the teaching machine and programmed learning (and hence owe much to the work of B. F. Skinner) combined with ideas that we normally associate with operations research and systems analysis.

With this brief introduction I should like now to discuss some details by considering the topics raised at the Unesco symposium on 'Utilization of Educational Technology in the Improvement of Science Education'.

Utilization of educational technology in the improvement of science education

There are now so many examples of the use of educational technology in schools at all levels that a choice of topics would have been very

difficult had it not been for the fact that Unesco brought together a small group of experts to write 'state-of-the-art' papers for the above symposium. A preliminary review of recent literature relevant to the improvement of science (and mathematics) education through the utilization of educational technology was also made by Unesco [72].

What follows is a resumé of the topics discussed at the meeting.

Programmed learning in science education

A paper with this title was prepared and presented at the Unesco meeting of experts by G. O. Leith of Utrecht [64]. In his summary he says:

> Programmed instruction is a set of techniques and principles for designing effective learning situations. A programme is therefore a means of ensuring that students achieve intended objectives. This is accomplished by carrying out analyses of objectives, as well as of the learning tasks involved in their achievement, of learning processes which students must employ, and conditions (including media) which will facilitate learning. In addition, the instructional materials and their environment must be set up and tested, that is, the programmer must try out his programme and obtain feedback to discover what modifications are needed for students to master the tasks. . . .
>
> It has also been found that social interaction may form part of a programmed environment so that co-operative learning and discussion will sometimes be indicated to achieve particular objectives. One aim of programmed learning—to individualize instruction—is nearer to fulfilment. It has been found that students may differ in learning style so that what is helpful for one kind of individual may hinder another and vice versa. In general, discovery seems to facilitate learning and transfer of extroverted students of secondary and tertiary level while introverts are favoured by more highly prompted strategies.

Leith discusses in detail many models of programmed learning and their possible application in developing countries. He concludes that programmers today show a sceptical disregard for what were, in the early days, considered the essential rules. Those which now appear to be critical are: (a) formulation of objectives and criteria of successful achievement; (b) analysis of tasks and design of learning situations; and (c) validation of learning situations and evaluation instruments.

Learning media: theory, selection and utilization in science education

This paper [65] was prepared by A. I. Berman of Copenhagen University. He attempts to do for educational media in a very thorough way what Bloom has done for objectives. That is, he puts the different media into categories.

He then procedes to describe and put the following media subsystems into the taxonomic classifications: filmstrip and slides, overhead projection, motion pictures, audio-tape recordings, television, holographic and other three-D displays, programmed learning, simulations and games, and printed materials. He includes a bibliography with 178 references. Here are some quotations from his summary:

If we were to devise a classification scheme for learning media, we might consider, along with the students, the importance of format. Our immediate questions would be: is it a diagram; is it moving; is it three-dimensional? The carrier of the display is of interest mainly to the teacher: is it produced by a 35-mm slide or by a plasma panel? One may agree with McLuhan—the medium *is* the message—if by this we mean the involvement of the student with the personally made line drawing, or with the lecturer on the screen who speaks to him alone. For media-oriented education, this is an essential point.

But science education demands more, namely, precision of display. The textbook drawing is no substitute for the holographic 'wraparound' image of the moon rock. The teacher's description of the life cycle of a flowering plant is no substitute for the time-compressld colour motion picture of the event. How to effect this display is the teacher's domain. One can, for example, delineate six distinct advantages of overhead projection over slide projection. One can discover several ways in which televised instruction is superior to live lecturing. The role that holography plays in science education is of unique interest: image reproduction through a microscope that is sharp at virtually all depth levels, shock wave interference, sharpening of blurred photographic images, and, above all, an 'isomorphic' rendering of an original scene that hardly can be described merely by printed words.

Computer-based science education

To illustrate his talk [66] Donald L. Bitzer brought to Paris an electronic computer display board which was connected by ordinary telephone lines to the computer in the United States.

One example (of many) he showed was how simulation techniques are used in a genetics course to teach students the laws of inheritance. The actual display showed pictures of fruit flies which were the result of matings of flies with known characteristics, e.g. vestigial or veinless wings, black, ebony, or striped bodies, etc. What the computer did was to use the laws of probability and to display, with almost zero time delay, the possible resultant offspring graphically (Fig. 7). The student records the results of these and other matings.

In his summary Bitzer says:

Students use computers in science education in two ways: they can *write* computer programmes in order to study complex systems and to learn numerical techniques; and they can *interact* with educational computer

programmes written by teachers. The first type of use is widespread, while the second has been severely hampered by the lack of suitable authoring and delivery systems.

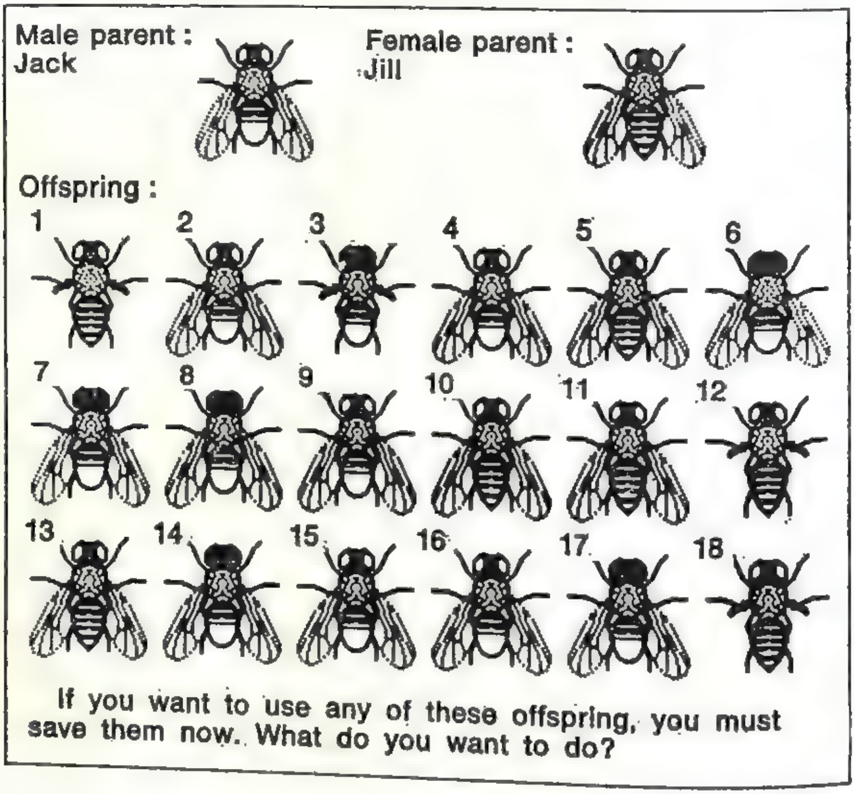

FIG. 7. Fruit fly genetics. Some of the offspring have white eyes and/or vestigial wings not seen in the parents.

His paper concentrates on the latter form of computer-based education and gives examples of materials written for their students by biologists, chemists, mathematicians and physicists. These materials reflect diverse teaching styles and strategies, including tutoring, simulation or modelling, and drills.

Bitzer observes that:

The problems of computer-based education include: (1) The need for an adequate terminal for student use. The common teletype is not adequate in science education—a *graphical* display terminal is required, a device which can rapidly display line drawings, graphs, and pictures. (2) The need for adequate computing power. A weak computer may only retrieve stored questions and recognize stereotyped responses. To go beyond this simple 'teaching machine' function requires enough computing power to

generate displays and problems and to recognize open-ended responses. (3) The need for good teachers to author materials without requiring the services of expert computer programmes. This implies the need for a suitable authoring language and system. (4) The need to make the cost of computer-based education far lower than it has been. Typical costs have been several dollars per hour per student, which cannot compete with the cost of a human tutor. It has been necessary to invent a new technology in order to make progress toward economically viable computer-based education.

The paper includes a thorough discussion of the problems of computer-based education and several examples of solutions to these problems from the author's wide experience.

The use of television in science teaching

This paper was prepared by J. Valérien of Montrouge (France) [67]. His summary says in part:

There has been a profound regeneration in the actual organization of science teaching: courses are based on a small number of more general concepts, and observation and methodology are replacing the traditional acquisition of knowledge.

How, in this setting, can educational television be used? Before answering the question, we must make two important distinctions: education may be in-school or post-school, and television may be closed-circuit or open-circuit.

For in-school instruction, closed-circuit television can be used in a single class, in one establishment or in a group of establishments by means of wire relay systems. Generally speaking, the total cost of this system is high and there are technical problems in the way of its widespread adoption. Its main interest lies in the teamwork done by teachers: they indeed are the ones who benefit most from it.

Open-circuit television, because of its scope and complexity, requires the assistance of professionals, who work in close collaboration with teams of educators to produce series of programmes for broadcasting. These may be stop-gap broadcasts, intended to deal with urgent problems (such as a sudden prolongation of the period of compulsory school attendance) which the traditional educational system cannot cope with; they may be supporting broadcasts, designed to supplement and illustrate the traditional lesson; or they may be broadcasts forming an integral part of an educational system that has been completely redesigned with the idea of using the television medium. (The Open University is at the moment the most striking example of this last type.)

The use of radio in science education

This paper [68] was written by John C. H. Ball of the School Broadcasting Division of the Voice of Kenya in Nairobi, a position in which

he has had ample opportunity to experiment with the medium of radio in science education.

An important argument he makes from experience is that radio is cheap compared with television, both at the production end and at the receiving end. Radio studios cost much less to build and equip than do television studios, while the radio receiver costs far less than the television receiver. A radio can be powered by a few cheap dry cells, whereas television requires a mains electricity supply or a set of expensive batteries. Ball points out that there must be few villages in Kenya without one radio set, and a very large number of villages with several sets, whereas there are no television sets in primary schools and few in secondary schools and colleges. This kind of information sets the tone of a paper very much concerned with what type of educational technology is appropriate in developing countries.

In his summary Ball says:

> Possibly the most difficult, and most important, skill required of an education broadcaster is the ability to understand a subject as his listeners understand it. Taking the word 'understand' in the widest sense, this means knowledge of the listener's way of life—his environment, his language, his culture, and the radio reception conditions where he lives. The technical and aesthetic production of a programme must derive directly from this knowledge. This is of first importance in developing countries, where the tendency has been to import or adapt material from developed countries. The uncritical use of this material has obscured the need for basic research into the learning processes and the environment of the local peoples.
>
> Where radio is used for science education in the classroom, careful thought must be given to the structure of the programme as well as its content. The devices of the radio producer—sound effects, fades, music, dramatization—must be precisely thought out and pre-tested. Where a practical element is built into radio lessons it should be exactly described and timed. The use of printed support material for teachers and pupils requires not only the precise integration of sound and sight, but also a knowledge of the 'visual literacy' of the listeners.

The author describes the benefits of the tape-slide technique known as 'Radiovision', the advantages of the use of the tape recorder and the possibility of using radio for adult education.

The paper has an extensive list of references to which I would add here only a single one which I have found very helpful, the journal *AV—Communications Review* (1201 Sixteenth Street N.W., Washington, DC 20036).

Integrated multi-media systems for science education which achieve a wide territorial coverage

The authors of this paper [69] were A. R. Kaye, lecturer in the Institute of Educational Technology, and M. J. Pentz, Dean of the

Faculty of Science at the Open University in the United Kingdom. It is characteristic of the Open University that this paper was written by a psychologist and a physicist. Most Open University course units are produced by a course team with participants who are specialists in subject matter, media and educational technology.

Kaye and Pentz have also written elsewhere:

> There is really nothing new about 'multi-media' teaching nor is teaching at a distance (e.g. in correspondence courses and external degree programmes) a recent development. However, it is only in the last few years that systematic attempts have been made to integrate the use of the different media within a framework of distant teaching. It is this combination which has led to the really novel developments in instructional design, in the roles of teachers and learners within such systems, and even in the nature of the material taught.
>
> To be fully effective, such systems need to combine centralized production of basic teaching materials (which may be distributed via postal and broadcast services) with some sort of local facility for developing personal contacts and face-to-face teaching.

Although great emphasis is placed in their paper on the experience of the Open University in the United Kingdom, there is a discussion of trends in the development of distant study systems in science based courses as observed in nine other institutions in the U.S.S.R., Australia, Japan, France, the Federal Republic of Germany, Poland, Canada and the United States.

Concerning some of these, Kaye and Pentz have written:

> There are several general points worth making at this stage. Firstly, that many existing multi-media distant teaching systems may have only a temporary or stop-gap role to play. This is perhaps especially the case in countries like the Soviet Union, Poland and Japan, where effective combinations of correspondence tuition, broadcasting, and face-to-face teaching have played (and still do play) a very important role in providing badly-needed educated and technically skilled man-power. But as conventional intra-mural facilities and trained teachers become more widely available, and as the backlog of adults who missed much of their schooling dries up, so these systems become less widely used.

Perhaps the most interesting and possibly the most useful chapter is the one entitled: 'The Influence of Educational Technology on the Design of a Multi-media Distant Study System—The Open University'. Here a great deal of detail is given on how the actual course components are developed, tested and produced, how television and radio are used (for about 10 per cent of the teaching load), how the problem of science practical (or laboratory) work is handled (partly by home kits), and how the difficult but essential task of student assessment and evaluation is handled with major assistance

from the computer. This includes evaluation of the courses as well. A list of thirty-six references is included.

Integrated multi-media systems for science education (excluding television and radio broadcasts)

This paper was written by S. N. Postlethwait of Purdue University (United States) and F. V. Mercer of Macquarie University (Australia) [70].

They begin by defining 'media' and then 'multimedia system' —one which employs a variety of media involving primarily three senses—seeing (visual), hearing (audio), and feeling (tangible), and combinations of these. They propose a classification scheme for media which should be compared with Berman's in an earlier paper.

Several systems, including the Keller Plan, the Southin System and the Guided Design System of West Virginia University are discussed, but of course emphasis is given to the Audio-tutorial System of Purdue University. For those of us who are enthusiastic about the potential of educational technology it is encouraging that the authors should have written:

> The individual nature of human beings cannot be over emphasized. Any good educational system must be based on the fact that 'learning must be done by the learner'. It must involve the student in the process and must always provide a high degree of flexibility and adaptation to individual needs. However, superimposed over this quest for individuality is the dependence of each student on teachers to guide, facilitate and stimulate him to engage in appropriate learning activities. Today's technology provides new dimensions to accomplish this end, and, when these new tools are used properly, they provide more intimate access to the teacher—they do not dehumanize.

Here are selected quotations from their summary:

> All learning is begun at the interface between the learner and his environment. Media systems permit us to provide the student with a simulation of original learning environments and, in some cases, improve the learner's perception through the mechanisms of magnification, amplification and time lapse sequences. The present capability of technology to store and retrieve audio and visual stimuli provides almost unlimited opportunities to develop learning programmes involving all basic communication tools. . . .
>
> A practical solution which will facilitate exchange is to develop self-instructional materials covering relatively small units of subject matter. These units or minicourses can provide the flexibility necessary for arranging instructional programmes in a variety of combinations suitable to many different learning programmes.

Educational technology in the professional training of science teachers

The author is Arye Perlberg of the Israel Institute of Technology [71]. He is an advocate of the systems approach and hence gives educational technology—as I have advocated elsewhere—a meaning which transcends the mere use of technology in education. In his summary he says:

> The rationale for using educational technology in the training of science teachers is twofold: first, it will enhance the effectiveness of training processes and, second, it will provide teachers with models which show how technology is used in learning processes.
>
> The following selected practices of educational technology in teacher education are discussed in some detail in this paper: application of systems approaches to the development of new teacher education programmes, use of behavioural objectives and performance criteria, learning modules utilizing multi-media systems for individualized self-instruction, laboratory simulations systems, microteaching, minicourses, observation systems of appraisal and instructional processes, systematic observation techniques, and the presentation of college-level courses related to teacher education through new media.

Selected comments

The concerns expressed by some participants in this meeting are summarized below. S. O. Awokoya, then director of one of Unesco's science departments, expressed the concern of less developed countries. He asked how, if he were an educational decision maker in Africa, he could get started in adopting the concepts of educational technology. Nigeria, he said, has no scientific infrastructure. He wanted to see spelled out how to apply media to a specific subject. He felt that a few paragraphs were needed on how to get a specific subject started in a specific country.

Professor Zacharias of the Massachusetts Institute of Technology felt that the omission of mathematics was serious. He though Unesco should express some value judgements. What's good, what's bad, in educational technology? What has been left undone? What will the technology of ten years hence be like?

Professor Isaias Raw of the University of São Paulo and Harvard University said, in his concern for the developing countries:

> In analyzing the use of educational technology in science education, a distinction is made between education and passive acquisition of information.
>
> The role sought for educational technology in science education is that of providing active learning and individualized instruction, so as to cope with different learning styles, learning rates and varieties of interest that could best be satisfied by tailor-made curricula. This is a goal barely

touched upon by the major stream of educational technology which is often conceived merely as a large-scale replacement for the lecture.

As most schools in the less developed world are devoid of even the simplest slide projectors, the priority should be there, not for the teacher-aiding tools, but for the low-cost laboratory equipment and other materials for student use.

The less wealthy countries could put more efforts in designing sets of multi-media units combining printed matter, short films, slides, and low-cost laboratory kits.

Professor Pentz made several recommendations to Unesco. One of the most important, in my view, was that an International Centre for Science Teaching should be established. As a medium-range objective it could run workshop-type summer schools for design and production of materials for learning involving teachers. As a long-term goal it could establish a really powerful computer terminal for computer-based instruction.

Professor Bitzer said, concerning computer-based education:

> Wait until you are ready. Large systems are more apt to be viable than small ones. If you start with a small system and it fails you are apt to lose interest in computer-based education. Only the rich countries can afford such failures. Educational institutions worldwide could send teams of teachers, planners and administrators to an established institution to be trained in the use of computer-based education. They could be sent back with access to computer terminals.

Evaluation of the performance of the learner and the system in science education

Evaluation linked with other educational factors

All the basic factors that lead to improvement in science education are interlinked. We may, for convenience, speak of them, in an abstract way, as if they could be isolated for examination and study—but in fact they do not have an independent existence.

Something similar characterizes the basic concepts of physics: space, time, matter, motion and energy. Real experiments deal with all of them together. No one concept has meaning alone. Try, for example, to describe a simple experiment dealing with motion without involving all the others.

We have already observed this to be true for the training of teachers. We found that no programme for the modernization of curricula succeeds unless the teachers are trained for it. Similarly, we will show, in this section, that improvement of methods of evaluation is both a cause and an effect in innovative science education programmes and must be considered along with the other factors for improvement.

Historical note

Concepts of evaluation and assessment have a long history and have changed drastically with time. They have been influenced by other aspects of education. In particular they depend upon such issues as (a) who (or what) should be evaluated; (b) who should evaluate; (c) how should evaluations be conducted; (d) why should evaluation take place at all; and (e) how can evaluation influence and be influenced by the educational process?

As an early example of testing outside of the academic sphere, J. C. Merwin [73] quotes Philip H. du Bois who pointed out that the emperor of China used a rudimentary form of proficiency-testing about 2200 B.C. to examine his officials every third year. The exact content or methods of testing at that time are not a matter of record, but in 1115 B.C. (during the Chan dynasty), approximately a thousand years later, the nature of the testing employed is known—job sample tests requiring proficiency in music, archery, horsemanship, writing and arithmetic were used.

From this ancient example of who tests for what, why, and how, we can jump to the present tests being given for automobile drivers' licences, as a modern example of non-academic testing which, in the state of California at least, is administered by an almost mechanically graded so-called objective test of the multiple-choice variety along with eye examinations and a practical driving test.

We shall be concerned mostly with academic testing, especially in science, but the same basic questions. Who? What? Why? and How? will need to be answered.

The question Why? is probably the most important, because it deals with the basic purpose or aim in evaluation and it will be seen that answers to all the other questions are influenced by the answer we give to this one.

Characteristics of old approaches to evaluation

If one looked at the purpose of examinations given in schools and universities a century ago, one would see that they were used to

generate a grading system that permitted separation of students into categories for the purposes of promotion, accreditation and/or certification. A final examination was often the main tool for evaluation. It was based primarily on a pessimistic, and sometimes cruel, inhumane and often elitist point of view conditioned by the fact that access to higher education was limited to a select few. The emphasis was on grading for the purpose of student placement. The final examination was a hurdle or a barrier.

There was very little chance for feedback to permit the results of examinations actually to help in the improvement of the learning process by way of their effects on the learner, the teacher or the system.

It was the learner who was being evaluated, often for rote learning of information dispensed by an authoritarian teacher. The student was a 'blotting-paper' which soaked up information meted out to him, sometimes with very little thinking, reflection or understanding on his part. His objective was to earn a grade that would permit him to pass. Often what the student learned was to be shrewd enough to guess what the teacher would ask him on the examination. The teacher did the evaluating but often the examination was 'set' by a national educational authority.

Characteristics or some new approaches to evaluation

What about the present? Having chosen some bad examples from the past, is it fair to choose only good examples from the present? Actual examples will be given later. For the time being let me state what I think is the ideal we are striving for.

At its best, the present approach to evaluation is more humane and optimistic. It seems to assume that every student can learn something and that he deserves some credit if he can demonstrate some achievement. It recognizes individual differences.

The motivation for evaluation now seems to be (ideally) the search for evidence of learning and understanding on the part of the student and not mere rote learning at that. Similarly some modern evaluation techniques seek evidence that teaching is being successfully carried out and that the system, as planned, is actually working.

As to who or what is being evaluated, therefore, the answer is that the student, the teacher and the system are all being evaluated. What is sought in the student is achievement and attainment in terms of knowledge and attitudes. We devise courses and techniques of teaching, then, whose objective is mastery of subject matter on the part of the student even if he has to do it at his own pace.

By what means is this evaluation being done? Broadly speaking, by all possible means with a view to continuous assessment in place of the old final examinations. There are techniques of self-assessment

and tests, quizzes, tutor-marked assignments, practical (laboratory and field) examinations as well as a final examination which is no longer the only criterion of evaluation.

As to who does the evaluating; as far as the student is concerned, it is done by the teacher, but often following institutional and government guidelines. Teachers also are being evaluated by students and by supervisors and, hopefully, the system is being evaluated by the general public, by parents and on the basis of standards set up by teachers' organizations as well.

Many attempts are being made to generate feedback by evaluation techniques which come early enough in the student's career to be of help to him, the teacher and the system as a whole.

Effect of behavioural philosophy

The underlying philosophy behind the new approaches to evaluation is that it is possible to alter behaviour by what Skinner has called operant conditioning. When the behaviour conforms to predetermined objectives—naturally called behavioural objectives—we say that learning has taken place and the success of the operation is measured or evaluated in terms of the degree of success that is achieved in terms of the objectives.

An educator—not known to me until recently—who appears to have had a strong influence in changing the role of evaluation in the United States is Ralph W. Tyler [74]. He apparently recognized the 'first flush of behavioural concepts' of objectives which were to have such a tremendous effect on concepts of education in general and on concepts of evaluation in particular.

As early as 1931 Tyler called for a close tie between objectives as a basis for instruction and as a basis for evaluation. He proposed specific guidelines for the formulation of these objectives saying that objectives need to be spelled out in statements of student behaviour which should then serve as guidelines for teaching and as a basis for testing. It seems to me that, perhaps inadvertently, he had laid the groundwork for a systems approach to education, educational technology, behavioural technology and programmed learning.

Nevertheless, because of the success that has been achieved by programmed learning, which was clearly inspired by Skinner's thinking, the bulk of the credit for inspiration of these new approaches, including the new ideas about evaluation, goes directly to B. F. Skinner.

It must be conceded that a science of human behaviour which can compare with physics or chemistry in its power has not yet been achieved but is clearly the goal of the behavioural technology school.

The critics of B. F. Skinner, especially since he wrote his book *Beyond Freedom and Dignity*, have been numerous and outspoken

and some have been individuals of considerable ability and knowledge. I am not competent to discuss the pros and cons of these philosophical arguments. What I do see is that in one form or another, the activities associated with programmed learning or educational technology and the systems approach are going to be with us for awhile. They all depend on a concept of evaluation based on the achievement of predetermined objectives.

Examinations based on objectives have already started to change teaching strategies and student learning behaviour patterns, and in some cases have helped students in achieving that ultimate goal—learning to learn. They have started to change administrative philosophy and procedures and have extended the use of the computer both as a teaching-learning tool and as an aid in the evaluation process. We are also aware that poor or improper evaluation techniques tend to nullify successes and advances in other sectors of the learning process.

Examples of projects and activities that promote improved methods of evaluation

Because, as I said earlier, every new educational project contains an evaluation phase, it was very difficult to choose from the large number of existing projects a limited number that would exemplify some of the current ideas for improved evaluation precedures. I decided to limit my discussion principally to approaches intimately connected with the names of three individuals, F. S. Keller, S. N. Postlethwait and Eric Rogers. (The concept of continuous assessment was discussed in the section on the Open University of the United Kingdom.)

Evaluation aspects of the Keller Plan

The Keller Plan is best known for its emphasis on individualized, self-paced learning but I will try to restrict myself to describing its methods of evaluating student progress.

It will, nevertheless, be necessary to describe the plan very briefly. Many such descriptions have been written by, for example, Protopapas [75], Green [76], Koen and Keller [77], and Kulik, Kulik and Carmichael [78]. Many teachers have experimented with the plan, which, incidentally, has been tried in at least eleven different subject areas. The following quotations are from the article by Protopapas [75]:

Keller summarizes the distinguishing characteristics of this plan as follows:

1. The student progresses at his own pace.
2. The student must exhibit mastery of a unit before he may proceed to the next unit.

3. Lectures are a means of motivation, not suppliers of critical information.
4. The teaching staff includes proctors (tutors).

The course material is divided into a number of units. Each unit consists of a brief introduction, a list of objectives to be mastered, student activities, and a list of study questions. When the student feels that he has achieved the objectives, he takes a unit test. If he passes, he is given the study guide for the next unit. If he fails, he reviews the test with his tutor and after 15 to 30 minutes he can take a second test on the unit.

There is no penalty for failing a unit test. Students are assigned to tutors, ideally on a ratio no greater than 8 or 10 to 1. The performance of the tutors is one of the two keys (the other being the quality of the units) to the success of the Keller Plan. The tutor is usually an undergraduate and thus in the same peer group as the students, a relationship which makes for excellent results.

The instructor prepares the study guides, the unit tests, secures and supervises the tutors, and oversees the entire operation of the Keller Plan. He is also continually seeking feedback concerning the quality of the study guide and unit tests and makes the necessary revisions immediately.

Protopapas then goes on to say:

My initial Keller Plan class registered for the course expecting the usual lecture program. At the first meeting the class was informed that the course content would include the identical material scheduled for the lecture sections, but that the material was divided into 14 units and the students were expected to proceed at their own pace. To pass a unit test consisting of 10 questions a student had to attain a 90 percent grade. A student who passed all 14 units entered the final examination with an A; 13 units, a B+; 12 units, a B, et cetera. This grade comprised 75 percent of the final grade, with the final examination contributing the other 25 percent. Students who finished all the units early were given the option of taking the final examination about one month early. This was greatly appreciated and served as an incentive for the students to finish the units.

For a thorough discussion of one experience in the teaching of physics by the Keller Plan at MIT see the article by Ben A. Green Jr [76]. Its summary is worth quoting.

The Keller plan (a self-paced, student-tutored, mastery-oriented instructional system) has spread widely in the six years of its existence, but mainly in teaching psychology. The paper reports experience with the plan in introductory physics. The results are strongly favorable; students report that they learn material more thoroughly and more efficiently. Lectures are used sparingly and mainly for motivation. Students may take as many as 20 written tests in a semester without complaint. Sophomore tutors grade the tests on the spot and have proven to be extremely valuable. The instructor's role is not to broadcast information but to manage a system and to write the necessary tests and other materials, as well as to give personal help to individuals in unusual cases.

A quotation from the experience of Koen and Keller [77] in teaching an engineering course may also be apposite.

> The student studies the units sequentially at the rate, time, and place he prefers. When he feels that he has completely mastered the material, the proctor gives him a 'readiness test' to see if he may proceed to the next unit. This proctor is a student who has been carefully chosen for his mastery of the course material.
>
> A fundamental part of this program is the requirement that the student be repeatedly tested and instantaneously graded whenever he feels he knows 100% of the material in a specific unit. He is placed in one of the following three categories on the basis of his performance on such a test:
>
> A. If he has no errors, he is given the next study unit with a word of congratulation.
>
> B. If he has one or two errors, he is channelled to a proctor who questions him as to his reasons for his wrong answers and rephrases ambiguous questions for him. By satisfactory performance at his stage, he may be passed to the next unit.
>
> C. If he has three or more errors, he is immediately recycled to restudy the current unit.
>
> No matter how many times a student is required to retake a unit, his grade is not affected; the only interest is that he ultimately demonstrate his proficiency over the material. All students who complete the course receive a grade of A.

The rules for grading vary with practitioners but high grades are given because the student works until he has really mastered the subject matter.

It is clear, then, that mastery of a subject area is a goal, that the evaluation procedure is almost continuous and is designed to assist the learner in the learning process.

Evaluation aspects of Postlethwait's audio-tutorial system

The title 'audio-tutorial approach to learning' suggests a strong emphasis on instruction via tape recordings and other audio devices but, in fact, the subtitle 'through independent study and integrated experiences' is indicative of other important aspects of the scheme. A thorough review of the entire system is given in the paper by Postlethwait and Mercer entitled 'Integrated multi-media systems for science education (excluding television and radio broadcasts) discussed earlier [70].

I will not attempt to describe the details of the audio-tutorial system but a few quotations from a book on the subject by Postlethwait, Novak and Murray [79] may be helpful.

> Emphasis on student learning rather than on the mechanism of teaching is the basis of the audio-tutorial approach. It involves the teacher identifying

as clearly as possible those responses, attitudes, concepts, ideas, and manipulatory skills to be achieved by the student and then designing a multifaceted, multi-sensory approach which will enable the student to direct his own activity to attain these objectives. The program of learning is organized in such a way that students can proceed at their own pace, filling in gaps in their background information and omitting the portions of the program which they have covered at some previous time. It makes use of every educational device available and attempts to align the exposure to the learning experiences in a sequence which will be most effective and efficient. The kind, number, and nature of the devices involved will be dependent on the nature of the subject matter under consideration.

The term 'integrated-experience', used with regard to the audio-tutorial system, is derived from the fact that a wide variety of teaching-learning experiences are integrated, with provision for individual student differences and each experience planned to present efficiently some important aspect of the subject. In the audio-tutorial booth, the taped presentation of the program is designed to direct the activity of one student at a time; the senior instructor, in a sense, becomes the student's private tutor. It is important to emphasize at this point that the tape represents only a programming device and that the student is involved in many kinds of learning activities. Further, it should be noted that those activities which by their nature cannot be programmed by the audio tape are retained and presented in other ways. For example, guest lecturers and long films are shown in a general assembly session, and small discussion groups are held on a regular basis to provide for those activities which can best be done in a small assembly. Flexibility and independence, accompanied by helpful guidance when necessary, are the key concepts of the approach.

In the audio-tutorial system the instructor's voice is available to the student to direct and supplement his study effort. This does not mean that a tape lecture is given! It refers to an audio programming of learning experiences logically sequenced to produce the most effective student response. Each study activity has been designed to provide information or skill leading to the proper performance of the next activity or else it builds on the foundation of knowledge previously laid. The overall set of integrated experiences includes lectures, reading of text or other appropriate material, making observations on demonstration set-ups, doing experiments, watching movies and/or any other appropriate activities helpful in understanding the subject matter. This system differs from the written programmed instruction and the conventional lecture-laboratory approach in at least two important ways:

1. Many subjects require student involvement in a variety of learning experiences. The conventional reaching system makes this adjustment through the scheduling of lectures, laboratories, recitations, et cetera. In the audio-tutorial system, these activities can be organized to a step-wise fashion with reduced disassociation in time and space encountered in the conventional approach, while at the same time, the logical learning progression characteristic of written programmed instruction is retained. Further, the learning events need not be limited to the vicarious participation of the student through his reading only, as in written programs. Hour-long lectures of necessity cover several units of information. Some of these topics

are covered more meaningfully when there is associated with them student involvement through experimentation, observation, textbook reading, and other appropriate activities. The limitations of time and physical facilities make this kind of integration unfeasible under the conventional system but clearly is practical under the audio-tutorial system utilizing audio-tape programming.

2. In the audio-tutorial booth the voice of the instructor provides timely information, definitions and parenthetical expressions with minimal effort for the learner. These helpful asides are often omitted from a student's study because of the inconvenience involved in looking up words, and because such thoughts seldom fit well as part of a written text. The tone of voice places emphasis on important points and expresses authority not sensed through reading the written word. . . .

The grading system is based upon the approach that all students achieving a specific level of accomplishment shall receive a commensurate grade. The objectives for each week's unit of study are mimeographed and made available to each student at the beginning of the study. Many educators disagree with this approach and express considerable concern when the percentage of failures is small. The audio-tutorial system is not a method for alleviating the strain on university facilities by eliminating students or a screening mechanism for students who are clever at 'beating the system.' This system will appeal only to those instructors who are anxious to enable as many students as possible to achieve their highest level of accomplishment. . . .

Eric Rogers on testing and evaluation

Professor Rogers is known as the organizer for the Nuffield O level Physics Project which he claimed was, among other things, a revolt against the very formal examinations that were once the rule in the United Kingdom and extended to many countries overseas from British examining boards. Even when alternative examinations had been secured in the United Kingdom, the traditional forms still held a strong hold in some developing countries.

I shall quote from a resource paper submitted to Unesco by Professor Rogers for a Working Party on the Improvement of Science Education with Special Reference to Developing Countries, held in Paris in 1969.

In the introduction, he says:

In devising any teaching system, we should look at the *sociology* of examinations: the interactions between examinations on the one hand and, on the other hand, teachers, teaching-methods, students' learning, students' opinions of the field of study, parents' opinions, . . . In addition to the dozen or more uses of examinations that we normally think of, there is one powerful aspect that we should consider in curriculum reform: *the effect of examinations* in telling students the aims of our teaching.

Suppose, for example, we aim at giving students an understanding of science, a feeling for the way science is done, a knowledge of science

as a fabric of experiment and theory. If *we end* with a tradititional examination that asks for memorized definitions and unthinking use of formulae, that will undo much of the good we hope to have done. Students infer our aims from our examinations and the next generation of students will hear and will be tempted to neglect our offer of good understanding, and will concentrate on memorizing.

Yet we can promote broader aims if our examinations ask for some critical thinking, using the material studied—and sometimes some imagination, going beyond the material studied—and ask for clear explanations in the student's own wordings. (Think how often a good teacher says, 'I never really understood that topic until I came to teach it.' We can apply that to young students, asking them to teach the examiner, *informally*.) We *can* make tests for uderstanding and even for enjoyment of science—though we shall have to sacrifice some precision of marking (reliability) for the sake of this gain of relevance.

The interaction between examinations and teachers is equally important. If we want to encourage teachers to change their teaching style, we may have little success if we keep the same examinations; but we can persuade teachers strongly and happily in a new direction if we provide examinations that fit the new suggestions and offer homework questions of similar build. Thus, in curriculum development or renewal, a change of examinations enables us to tell students our new aims and enables teachers to change their teaching.

He then discusses examinations and the beginning of science for children in developing countries:

The young child, bringing his outlook on the world from home, and conditioned from infancy to judging his own behaviour, and developing it, according to parental approval or disapproval, will judge his early school lessons partly by his world outlook from home, partly by his teacher's approval. Beginning science with acquaintance, when the teacher shows a delightful demonstration or provides equipment for enjoyable experimenting, that offers experience but it does not in itself provide the important element of approval/disapproval which will determine any lasting educational effect. Attention, encouragement, sympathy, praise: all these can reinforce early learning of science and they are in a way simple, informal acts of testing—a judgement-exchange between child and teacher.

As the teaching progresses, the teacher asks questions: these are both aids to learning and at the same time simple examinations. Making comments, asking questions, giving tests, setting examinations, providing external examinations: all these not only evaluate progress (satisfying some needs of teacher and school), not only act as mirrors (to reflect to each pupil a picture of his progress), but they also provide feedback to the pupil, telling him what kind of science we were trying to teach. This then influences the direction of his learning—an influence so powerful that it may be the key to progress in changing the nature of science teaching. If, in early stages, the tests ask for simple facts alone (what I call 'cheap recall') or for mechanical use of memorized formulae and definitions, the pupil may decide that success in science comes from prolonged obedient rote learning. If we ask for informal descriptions of experiments and,

later, some reasoning and putting-together of several pieces of knowledge ('expensive recall') we are telling pupils insistently a different view of science.

As motives we cannot be sure the child will want to be scientific, or even to do experiments or make measurements or enjoy finding a law. The only emotion I think we can be sure of, world-wide, for our purpose, is *pleasure in success*. . . .

Rogers goes on to suggest examination manufacturing seminars for teachers as a special strategy in curriculum reform:

Since a new curriculum or new aims or ways of teaching will need consistent *homework problems*, tests and examinations, it is important to offer teachers some training in making questions or problems that fit the new teaching. But I have found that such a seminar goes far beyond its immediate aim: it provides a very powerful way of educating teachers in all aspects of the new scheme.

We invite a group of teachers (perhaps with a few administrators), say a dozen in all, to a conference to manufacture questions for examinations (also for homework or other teaching uses). After a first meeting to set forth the aims and needs, and to give some suggestions about types of questions, members of the group disperse to make up one or two questions each. When they re-assemble, one starts by reading his question: then neighbours start objecting, criticising, defending, changing, and adding to it. After an hour or more we have only discussed two or three questions, because we have ceased to be a question-factory and have become a philosophical discussion group, vigorously exposing, comparing and discussing our teaching aims. I shall have acted as a chairman at first to encourage the discussion and criticism of questions: but later I retire into a less active position, merely adding a few comments on aims and feasibility of methods. In practice this turns out to be one of the most powerful methods of briefing teachers in new and different teaching programs. For its initial activity in encouraging participants.

Since participants are encouraged to tear each other's questions critically to pieces, I call this gathering a 'shredder'. The name has proved useful in encouraging frank criticism from the start, and in concealing the philosophical aspect which will appear—and which is a major use of the gathering.

Teachers invited to discuss their philosophy of teaching in a conference usually hesitate, or else launch into unrealistic aims. But teachers invited to an examination-making shredder soon discuss realistic aims—discovering new ones and re-examining old ones, while a chairman can guide the arguments in useful directions.

Professor Rogers conducted a Unesco seminar on activities of this sort in Montevideo from 4 to 16 January 1971. A 119-pages report entitled *Improving Physics Education through the Construction and Discussion of Various Types of Tests* is available from Unesco [80]. It contains many examples of questions generated by a group of physics teachers under his direction.

The design and production of materials and equipment for science education

It has been my intention, in this chapter, to give examples of current activities in areas of special importance. I have done this by choosing institutions, projects or courses whose activities illustrate the points in question such as integrated science, teacher training, educational technology and evaluation.

Perhaps there is no better way to prove how important the design and production of materials is considered to be in the science teaching field than by noting that all of these projects and many others which we have not had space to discuss devote a good portion of their effort to materials design and, in some cases, to production.

It would be difficult to make a choice among these projects as examples in the area of materials design because so many variables are involved, e.g. geographic distribution, academic level, academic discipline, stage of economic development of the country involved, and so on. We would run the risk of repetition, in any case, because many of the projects already discussed would be bound to appear again.

In the light of this what I propose to do in this section, after defining terms, is to limit myself to discussing just one aspect of materials design of very special importance and then naming some projects which the reader may consult for further details.

The area of special importance I have chosen is the involvement of teachers and prospective teachers in the process of design of new materials and equipment. Inevitably it will also involve us in several other areas such as choice of content of the courses for which the materials are designed.

The problem is this. Regardless of how the new materials are invented and produced, eventually teachers have to use them. This they are often reluctant to do because they are not acquainted with them. They need to be trained to use them and we have seen that the training of teachers in the use of new materials has become an important activity in science teaching improvement.

How can you motivate teachers to want to use the new materials? One way is to get them involved in the actual process of design, invention and development of the new materials as part of their pre-service and in-service training. If, for example, they become the co-authors of, or at least the early experimenters with, the new materials and devices, the probability that they will want

to use them is high. This theme will be developed after we discuss the meaning of some terms.

Definition of terms. Software and hardware

By materials, we have in mind not only things such as textbooks, laboratory manuals and self-instructional booklets, but also films, slides, film strips, and transparencies for the overhead projector as well as magnetic tapes for sound and sight such as video cassettes and closed- and open-circuit television. Materials such as these, which contain the message of a course, are often called 'software'. Their content depends on the objectives of the course. The equipment needed to project, play back or otherwise transmit this message is the 'hardware' of the educational process. It includes the film and slide projectors, the tape recorders and playback units, the television cameras and viewing monitors, the radio stations and their equipment.

The types of software and hardware that have been mentioned thus far are related to the teaching-learning process by way of words, sounds and images.

But it is also possible—and in science teaching necessary—to have the students learn from experiences and experiments. The materials, in the case of the biological and earth sciences, include specimens from nature. But in physics and chemistry we run into the need for laboratory equipment and expendable materials. They are all, of course, forms of hardware but the term 'hardware' in an educational technology framework more often has the connotation of equipment such as motion picture projectors and television cameras —used to convey a message.

In the over-all learning process, pencils, paper, chalk, books, films, tapes, cameras and projectors are all examples of materials and equipment—the things of learning—the design and production of which is our immediate concern, regardless of whether or not they are software, hardware, or both.

Design, development and production

By design I have in mind the process of invention and creation as well as the experimental testing of prototypes that is associated with the word 'development'. The result of this process may be a single manuscript or tape or film or piece of laboratory equipment. This is in contrast to the process of production by means of which many copies of the prototype are generated. In a number of countries the production process is handled by commercial companies. In others it is run by government enterprises.

In both advanced and developing countries the numbers of

pupils, students and teachers involved are very large. Expenditures for education are high. The needs for materials and equipment may, therefore, be very large. In one region of India alone, for example, 100,000 secondary schools have to be supplied.

The uses to which motion picture and slide projectors, cassette tape recorders, inexpensive transistor radios, video cassettes, recorders, electronic calculators, computer-based learning aids, radio and television stations, and orbiting satellite communication systems can be put are much greater than those needed for education alone. The motives for their commercial production even outside the education establishment generate a momentum for mass production. There is therefore a tendency for production of hardware to outstrip the development of the corresponding educational software.

The motivation, in the form of financial support, to produce quality software is not as high as that for producing hardware that has multiple uses. We now have, for example, commercially developed video-disc devices available but essentially nothing worthwhile as educational software to put into them. It is already possible, with a video-disc attachment, to convert every home television receiver into an excellent home movie projector to play back the programme of your choice for entertainment, for self-instruction or both.

Responsibility for design of software

The problem is to determine who will finance and motivate the design and development of the software that goes into the machine? For science education this task requires the collaboration of scientists, who are the subject matter specialists, of educators including some of the actual teachers who will use the materials, of educational technologists and of the specialized technicians who know how to put such teaching programmes together; the kind of teams, for example, that made the PSSC films or the Open University BBC broadcasts. Who will provide the support for this important task in the future?

The thesis of this section is that the greater need everywhere is at the software level. The production of hardware, except for inexpensive laboratory kits, already has its proponents but the creation of high quality educational software will require a conscious effort and support from the educational authorities in all countries.

It is, fortunately, possible to begin by creating teams to generate software to be used with inexpensive hardware. These same teams can, at a later stage, utilize their talents to produce software for the more sophisticated educational hardware. It is possible, for example, to learn the art of presenting synchronized audio and visual material by preparing inexpensive 35-mm slides or transparencies for the overhead projector to be used in conjunction with sound tapes recorded and played back on inexpensive cassette tape recorders. The art of script

writing can be learned and practised in this inexpensive way first, and later, if necessary, practised in the production of films and television programmes.

The important thing is to create large cadres of individuals knowledgeable in the design process associated with the creation of software. From this large pool of people with competence in the art of communication will come the staffs of future educational establishments utilizing all the modern media of educational technology.

A particular group that stands to gain much from participating in the design process consists of the ultimate users of the materials —namely, the teachers themselves. I will illustrate later how teachers might become better teachers by participating in the process of designing and developing new courses and new learning materials. But, before that, I would like to summarize the main steps involved in designing new courses.

Designing new courses

In designing a new science course, one would generally start with the following:

Identification of the purpose and specific objectives of the course.

Analysis of the pre-requisite knowledge, abilities, attitudes, learning patterns and readiness for abstract thinking on the part of the pupils who will be taking the course, taking also into account the effect of local cultural factors.

Analysis of the capabilities of the available teachers, especially regarding their ability to use successfully the teaching strategies to be built into the course.

Analysis of other relevant local constraints.

Survey and critical analysis of existing ideas and materials related to the subject of the course, especially those generated by leading science curriculum reform groups in and out of the country, to be used as possible resource materials for local adaptation.

On the basis of the above, one would then continue with the following steps:

Development of new ideas, both through adaptation and original creation, regarding content, approaches, teaching and learning strategies, examples and non-examples required for concept formation, etc.; and planning of the laboratory work, demonstration and other activities of both pupils and teachers.

Design and preparation of the required new materials (texts for pupils and teachers, laboratory kits and apparatus, other learning aids using all appropriate communication media, supplementary reading materials, etc.) and development of these materials in prototype quantities.

Preparation of adequate tests for the evaluation of the achievement of the pupils as they work with the new course.

Then, having prepared the above prototypes, one would proceed with:

Trials with the new course materials in a number of experimental schools, collection and analysis of the feedback, and evaluation of the results.

Adjustment and revision of the prototype materials in the light of the results of the evaluation.

The above process of designing a new science course and preparing suitable learning materials requires the participation of scientists, teachers, psychologists and specialists in various educational media and techniques. Certainly the teachers—those who will be teaching with the new materials—in order to ensure the 'teachability' of the new course. This has been done in one way or other, in the case of all the recent curriculum development projects, with increasing teacher participation in the more recent ones. In the course of time, it was found that the participation of these teachers did not only contribute to the quality of the new courses, but was also of considerable training value for the teachers themselves in helping them to become better teachers and thus ensuring a more effective implementation of the new courses.

Obviously, for reasons of both time and money, only a limited number of teachers can have a chance to participate in all aspects of a curriculum development project for its full duration, if the project is attempting to develop something like a one-year course. Besides, if the participation of a teacher is meant to be mainly of training value to himself, it is probably not necessary that he participate for the whole duration of a large project. He might instead concentrate on the design and development of a fairly small part of a course—a self-contained unit covering perhaps one main concept or activity. Each of these modular units might correspond, for instance, to something like 3 to 8 hours of student activity; or perhaps up to 10 or 20 hours in the case of the longer units.

Not many years ago, it was still possible to find both national and international projects with a focus either on (a) curriculum development, course design and production of new educational materials, or (b) teacher training and re-training. Gradually, as the close interrelationships between these two aspects began to be better understood, more systematic approaches developed, and one finds now projects which take an over-all view of reform in science education—or indeed in the whole system of education. Also, as the efforts for better teacher training and the efforts in designing new courses and new materials were brought together, various forms of modular approaches began to emerge. In giving examples, I will limit myself for the sake of brevity to some of the Unesco-sponsored projects in the area of science education.

About ten years ago, Unesco launched a series of experimental projects on new approaches in the teaching of science, beginning with one in physics in Latin America, one in chemistry in Asia and

one in biology in Africa. The physics project [34], [81, p. 25-32] began with a first phase of one year during which twenty-five Latin American physicists and teachers of physics worked together in São Paulo under the guidance of various specialists provided by Unesco. Their task was to design and develop part of a secondary-level physics course and to prepare the corresponding learning materials. The subject chosen was the 'Physics of Light', and the participants were asked to explore the combined use of programmed instruction, self-instructional texts, low-cost laboratory kits, and films. By the end of the year, a preliminary version of the books was printed and a sufficient number of copies of the laboratory kits and of the films were made, in order to have their authors and other teachers test them more systematically under school conditions.

Although intended as a curriculum development project, it soon became clear that all the participants—even those who were contributing less toward the preparation of the new materials—were benefiting greatly in acquiring both knowledge and skills, as well as self-confidence, for the application of the new approaches in their own teaching. For the benefit of the students to whom the course was addressed, the group decided to divide the course they were designing into several semi-independent units. This turned out to be advantageous to the members of the group too, as every one of the participants could thus benefit from all aspects of the work, even if working only on one of the units. The advantage of this modular approach has been further confirmed [82], [83] by the fact that some of the units developed have been used more widely than others.

The next project in this series, started in 1965, was the one on chemistry [84] in Asia. With the lessons learnt from the previous one, it was decided that the materials to be produced in this case were to be mainly for the use of teachers (in the form of resource materials, teachers guides, etc.), plus laboratory kits and 8-mm films for the pupils. Again, a modular approach was used so that the various units that were developed could be used in different ways under the varying circumstances prevailing in the countries of the region.

The biology project [85] in Africa was started with a one-year phase for anglophone countries. The initial work was done by one group which stayed together for close to a year in one location. In the subsequent phase for francophone countries, however, the work was shared among various groups and various locations: four workshop-seminars were thus held in four different countries, with a duration of two months each and with intervals of about three to six months between them. This allowed a larger number of teachers to participate, and made it easier to ensure that the materials developed were to be relevant to the particular needs and local characteristics of the countries in which they were to be used. The project came up with materials corresponding to about thirty units or moduli, and for each of them one or more of the following were prepared: teacher's

guide, sets of colour slides, 8-mm and 16-mm films, notes on practical work, supplementary reading materials.

This modular approach lends itself rather well to the participation of teachers in curriculum work. In this connexion. I will quote some paragraphs from a paper by N. Joel entitled *Improving the Initial and In-service Education of Science Teachers by involving them in the Process of designing New Science Courses* [62]:

By working—either individually or in groups—on the design and development of modular units, teachers can have the opportunity to acquire first-hand experience with a wide spectrum of educational problems: definition of objectives, outline of teaching and learning strategies, choice of media, design of materials (both written and others, such as kits), preparation of tests, school trials with the preliminary versions of the units, their evaluation, etc. It is hoped that a teacher who has dealt himself with all (or most of) these problems, even if he has covered only a few small units, may then find it possible to generalize his experience to other parts of a course. It would certainly be much more difficult to do it the other way round: to have him work on a complete course in only one particular educational aspect (for instance, construction of laboratory kits), and then expect him to be able to deal with all the other educational aspects on which he has had no direct experience.

Obviously, not every teacher can be expected to be successful in his first attempts at designing, developing, trying out, evaluating and revising a few of these sets of modular units—each set dealing with a given concept or activity. He will learn as he progresses. The whole exercise is meant to be a training opportunity: an introduction to a field in which the professional teacher should work continously. And, as he goes through it, one would hope that he will acquire at least some of the following (or, if not, at least become motivated to acquire them through further study and work):

familiarity with basic knowledge on the process of learning, relevant to science education;

experience with the analysis of learning objectives of various types (facts, skills, concepts, attitudes, etc.);

knowledge of the potentialities and limitations of various types of learning situations (lecture, demonstration, laboratory work, discussion, tutorial, film, etc.) in relation to types of learning objectives;

knowledge of the suitability of various means of testing in relation to types of learning objectives;

experience with some media and the corresponding production techniques, and awareness of the relevant characteristics (cost, availability, versatility, reliability, etc.);

acquaintance with some of the products of a few selected science education projects, examined in relation to their explicit objectives and their different approaches;

awareness of the impact of social, cultural and language factors on the learning process, especially in connection with the adaptation of methods and materials initially designed for use in other countries.

It might seem, at first sight, that the institutional arrangements required

in order to put these ideas into practice would be very complex and expensive. This need not be so if use is made also of existing institutions and facilities.

For instance, work as proposed in this paper could well be carried out partly in teacher training colleges, as part of the regular training process of future teachers. Other groups could work along similar lines also in science departments and education departments in universities.

On the other hand, if participating in the design of new science courses—in the form of modular units as proposed in this paper—is to play an important role in the training of teachers, then, clearly, more attention should be given to it also during the period of initial training of teachers, that is, in teacher training colleges. In many cases, this will require changes both in curricula and in deep-rooted working habits. Fortunately, the idea that not only pupils but also future teachers should be 'learning by doing'—rather than just hearing about what to do and how to do it—is gaining ground fast. And therefore one can expect a trend towards more active programmes in teacher training colleges, including also the direct involvement of the future teachers in the design and development of learning materials in the form of modular units. The trainees could of course start by analyzing and evaluating existing materials of different kinds and levels, before they embark on the development of new ones. There are also production techniques to be learnt and communication problems to be understood. . . .

In trying to bring this kind of work into teacher training institutions, one should not forget the preparation and detailed analysis of various types of testing materials. In fact, this can be of considerable training value, as in the case of Professor Eric Rogers' workshop seminars [80] mentioned earlier.

From design to large-scale implementation

The earlier discussion of ways in which the training of teachers can be improved by involving them in the materials design process gave us, in passing, a glimpse at how the concepts of systems analysis and educational technology have influenced the planning, design and testing of prototype materials.

It remains to suggest how these new materials can be mass-produced for large-scale implementation. This depends on the type of economic infrastructure that supports an educational enterprise which varies tremendously from country to country and even within the states of a given country. It goes back to the question of who has the authority to make the decisions on what materials and equipment will be used.

In countries where the educational system is highly centralized, even the design and development of prototypes is in the hands of a permanent institution such as an Academy of Pedagogical Sciences. The prototypes developed and recommended by them are mass-

produced (effecting a great saving in cost) and utilized uniformly throughout a whole country.

In countries where there is a minimum of centralization, the actual production of materials is done by commercial companies for profit. Books and films for the elementary grades have to be approved by special boards at the state level (I am thinking of countries like India and the United States with several states within the country) and then bought in mass quantities for the schools.

In such countries a private individual may write a textbook on his own initiative and have it published by a private firm which in turn tries to 'sell' it to the authorities for mass use.

This kind of system, because of competition, often produces a great variety of textbooks and other materials to choose from and the 'market'—meaning the laws of supply and demand—determines which books will sell and which books will not sell.

A certain amount of chaos attends the procedure and one is never certain that the materials were produced with the real objectives of the course in mind although textbook manufacturers have their 'scouts' in the field so as to remain aware of what the important trends really are and turn out a product that satisfies the demand.

A slightly more orderly procedure has evolved as a result of the science curriculum reform movement that began in the fifties. First, government support made it possible for projects to be formed in which the people knowledgeable in subject matter and in how to develop books, programmed learning manuals, films, slides, kits, etc., were engaged. With small editions, trials were run with limited numbers of students and teachers. On the basis of what was produced, the rights to publish were given to a limited number of publishers and equipment manufacturers. Eventually other publishers and manufacturers began to produce their own books and materials, highly influenced by the original materials put out by the reform groups, and a great variety of materials flooded the market giving the potential buyer much to choose from.

The influence of the original 'big five' projects: PSSC, BSCS, CUBS, CHEM Study, SMSG and all the subsequent projects can still be seen in the textbooks and materials that have appeared not only in the United States but round the world.

Some particular cases of mass production with special reference to developing countries

In terms of the quantities of materials published, the Unicef project merits particular mention. When Unicef decided to assist in the teaching of science, especially at the primary grades in developing countries, they discovered the great need for science teaching equipment. With expert help, they produced a list (called the Eve list) with items they

could stockpile for distribution to developing countries round the world. They collaborated with Unesco, and eventually produced a modified list [60], [61] from which by now millions of dollars of equipment have been supplied to schools in developing countries. Unicef maintains a huge warehouse of equipment in Denmark, from which shipments can be made all over the world.

A particularly interesting project in which extensive use has been made of the Unicef equipment is the Papua New Guinea project mentioned above. Of course, many of the other science teaching projects funded by UNDP have a small equipment component to be chosen by the chief technical adviser of the project and his staff.

Another interesting development has been the growth of small materials production industries that have sprung out of the Unesco pilot projects. The firm of Equipamiento Científico y técnico (ECYT) in Argentina is a case in point. Brazil has produced thousands of science teaching kits that have been sold all over Latin America and in other countries. They originated in the old IBECC project whose successor, FUNBEC, is carrying on successfully.

An interesting project in Fairfax County, Virginia (United States), directed by Douglas M. Lapp, has concentrated on having children work at mass producing equipment for the schools in their own community [86].

A regional seminar on school science equipment was convened in New Delhi in 1972 by Unesco in co-operation with the Government of India and Unicef [87]. Numerous experts in the design and construction of science teaching equipment have been sent by Unesco to developing countries with assistance from UNDP.

In conclusion, we refer the reader to all the projects mentioned earlier for suggestions on how to make the transition from design and development of prototypes to the mass production of materials. But I repeat, the future success of new materials will depend more on the emphasis that is given to the development of software than to hardware.

Other references in which design and development of materials for science teaching are considered are given in the bibliography [88], [89], [90], [91], [92], [93].

Experiences and experiments in the laboratory, the classroom, the home and the field

Experiences and experiments

We have already said that in all the innovative projects for science teaching improvement there is a move away from rote memorization of facts to learning through a more direct interaction between student and nature. This need not always take place in the formal setting of a laboratory. Indeed, to promote curiosity, the student may be encouraged to observe many aspects of nature informally before taking and analysing data as he is intended to do in the laboratory. I will call the informal observation an 'experience' and the more structured activity requiring the collection and analysis of data an 'experiment'. I believe students in science courses should have many experiences and should perform at least some experiments.

Observing the rainbow and the order of its colours is an experience. The measurement of refraction and dispersion in the laboratory is a related experiment. Noting that the lower notes on a xylophone are produced by the longer sticks is an experience. Measuring the frequency of the different tones is an experiment. Illustrations of experiences in biology, chemistry and earth sciences abound and may occur in the field or even at home but the refined observations and measurement of the related experiments often (but not always) require the tools of a laboratory: the microscope, the analytical balance or the Bunsen burner. For lack of these instruments, students are often deprived of a laboratory experience, especially in developing countries, but we have noted elsewhere that meaningful quantitative experiments and certainly many experiences can be performed with inexpensive equipment.

There is, in my view, no question about the importance of experiments in the development of the structure we call science but there is still room for discussion about their role in science education. A university physics course with laboratory has, in the past, been a requirement for entry into medical school, for example, but recently the need for physics laboratory experiments in pre-medical training has been questioned. Do they really help in producing a better doctor?

Opinion is divided on this matter partly, no doubt, because the behavioural objectives of many laboratory courses for such students have not been clearly spelled out.

Without trying to settle this question, my own belief is that experiences and experiments can add a great deal of excitement and

motivation to the learning of science, can provide many examples and counter-examples to clarify scientific concepts and in practice can generate certain skills and approaches that may be useful even to students who will not become professional scientists. In other words, experiences and experiments are valid parts of an effective teaching-learning strategy in science.

In the real world of science not all scientists perform experiments. It is reported that Maxwell—who has been called the greatest theoretical physicist of the nineteenth century—was asked how he was able to bring to such elegant completion his work on the electromagnetic equations and that he answered simply, 'by thinking about it all the time'. But on another occasion he had said: '. . . before I began the study of electricity I resolved to read no mathematics on the subject until I had first read through Faraday's *Experimental Researches in Electricity*'. So there was a division of labour, but someone had to perform the experiments. It is difficult to imagine that a theory of electromagnetism could have evolved without experiments.

My point of view is that all students, especially in the developing countries, have much to gain from experiences and experiments performed in the home, the field, the classroom and the laboratory. The reliance on personal observation, the experience of coming to conclusions from data personally acquired and of learning how to transmit them accurately in writing, all make a positive contribution to the student's education.

Since science has expanded so rapidly it is impossible for any student to perform even 10 per cent of all the crucial experiments that undergird the basic sciences. But a very vivid acquaintance with them can be acquired through live classroom demonstrations and the use of films and other audio-visual aids as well as through computer simulations of experiments such as those of the Mendelian heredity computer simulation exercise shown in Figure 7 (page 158). In the remainder of this section we shall give some examples of projects that illustrate different ways of linking experiments and experiences with the rest of the science education programme.

It has been very difficult to choose from the several hundred science teaching projects that exist a small number of illustrations. I have been forced to choose at most two or three in each of the areas of laboratory, home and field and have added a few words about experiments or substitutes for experiments in the classroom.

I have tried to choose projects that exemplify the combination of experiments with other aspects of learning such as individualized instruction or the use of audio-visual aids, and I have tried to give examples from different countries and at different academic levels. There are so many parameters that the final choice often rested on projects that were of personal interest to me either because I had seen them in action or because I felt they were of particular world-wide importance.

Projects stressing laboratory experience

Introductory Physical Science (IPS) (p. 651)

To save space I shall refer the reader, wherever possible, to the description of the project in the *International Clearinghouse Report* of 1972 [24] and will limit myself to a brief summary here. The number within parentheses following the course title refers to the page number in that report. See, for example, IPS (p. 651) above.

This course had its genesis in the Physical Science Study Committee (PSSC) physics programme from which it was learned that an understanding of the nature of experimental physical science and some basic scientific skills could and should be acquired by the students before they take physics courses at the senior high school. IPS serves as the starting point for a laboratory-oriented introductory physical science course designed to equip students to meet the challenge of modern senior high school courses in science.

The unique characteristic of the project is that it provides a laboratory-centred course for junior high school students. It was designed for, and is used with, students having diverse cultural and socio-economic backgrounds and representing all ability levels. The over-all objective is to give all junior high school students an initial knowledge of physical science and to offer some insight into the means whereby scientific knowledge is acquired.

A key to the success of the project was the well planned and executed textbook which is essentially a laboratory guide for students. The laboratory equipment and apparatus were designed to be simple, inexpensive, versatile and effective, achieving a certain functional beauty in the process. Other important materials include the teachers' guide, achievement and laboratory tests, films, film loops and a periodic newsletter.

Although the project began in 1963 with a small team of teachers and investigators under the direction of Uri Haber-Schaim, by 1966–67 over 100,000 students were using the textbook. By 1972 it was estimated that over 1 million students were using the various materials in Canada, Japan, Korea, Brazil, Spain, Uruguay, Mexico, Peru, Venezuela, Italy, Turkey, Philippines and Afghanistan—several of them in translation.

A sequel called IPS II has been designed to prepare physical science students for the study of biology. The project is an admirable example of how PSSC ideas stimulated analogous activities at the pre-high school level. The course derives much of its excitement from the simple elegance of its experiments, from the economy of parts used for laboratory materials and from the way the student is led on intellectually by the lure of experiments which he performs himself.

The Intermediate Science Curriculum Study (ISCS) (p. 657)

A junior high school laboratory-oriented project has also had wide acceptance. It began with a pilot study in 1964 headed by Ernest Burkman in Tallahassee, Florida. In 1972 it was estimated that almost half a million students were using ISCS materials in national schools in Australia, Canada, Japan, the Philippines and Puerto Rico, as well as in American schools in Belgium, the United Kingdom, the Federal Republic of Germany, Guam, Iran, Italy, Norway, Spain, Turkey and Uganda.

What makes this course unique is that students using ISCS materials progress at different rates and through different instructional pathways depending upon their interests, abilities and previous experiences. The materials have been designed so that this can be accomplished in ordinary science classrooms (including laboratories) by teachers with limited special training.

The key words are, therefore, individualized instruction. The principal objective is to provide students with materials written in a self-pacing style and to determine their own success by means of self-evaluation tests.

The laboratory materials are geared to investigation and to other supplemental materials used in 'excursions' which give both advanced and below-average students alternate pathways to follow.

The content for the seventh-grade course is organized around twin themes of 'Energy, its Forms and Characteristics' and 'Measurement and Operational Definitions'. The organizing themes for Grade VIII are 'Matter and its Composition' and 'Model Building'. The models help interpret physical, chemical and biological situations. The ninth-grade course is composed of a series of discreet 'investigations' each designed to occupy the student for six to eight weeks. Topics for the ninth-grade investigations are drawn primarily from earth and biological sciences. Several of the new tools of modern educational technology, including computer-assisted instruction, have been tried.

We shall have more to say about the role that computer-simulated experiments can play in a later section.

The Unesco pilot projects in the basic sciences

These have already been discussed earlier in this chapter [34], [82], [84], [85]. What is worthy of note here is the strong emphasis they placed on 'hands-on' experiments performed by students using kits of materials developed by the regional participants in the project. Some of them also pioneered the utilizing of what were at the time very new techniques such as programmed learning, films, film loops and television, all with materials designed and developed by the pilot

project participants. To this day we know of no other projects that have linked programmed learning with experiments as closely as did the Unesco pilot projects in physics and chemistry.

Projects stressing work done in the field

Australian Science Education Project (ASEP) (p. 128)

We have already mentioned this project in connexion with integrated science earlier in this chapter, so we shall stress here only its unique approach to experiences and experiments performed mainly in the field. An environmental scheme forms the basis for the choice of topics emphasizing the environment as seen by children (Grades VII to X, or VIII to X as appropriate to the junior secondary schools in Australia) and extending beyond traditional science subject matter. (This will be seen when we list some of the topics chosen.)

The three ideas which make this a unique project, it seems to me, are: (a) an integrated approach; (b) stress on the environment; and (c) experiences and experiments performed by the students in the field rather than the laboratory.

The titles of some of the units will illustrate these three points.

Stage I units: Cells, the units of life; Earth's changing face; Electric circuits; Energy and change; Forces, made to measure; Males and females, mice and men; Minerals and crystals; Pigments and acidity; Places for people; Plants; Safety in science; Tunning in with the senses; Water; World of the soil.

Stage II units: Atoms; Charge; Digging up evidence; Foods, life in fresh water; Light forms images; Machines; Microbes; Petroleum; Signals without words; Skin and clothes; Sticking together; Weather.

Stage III units: Australians—past and present; The Australian scene; The earth; Genetics; How many people? The human machine; Metals; Polymers; Seashores; Solar energy; Traffic; Where did humans come from?

The teacher is supplied with a teachers' guide profusely illustrated, to help him or her guide the student through his field experiences and experiments. The student is supplied with a record book to keep the data collected in the field in a systematic order.

The whole course could be studied with profit by anyone interested in developing a field-based course.

African Primary Science Programme (APSP) (p. 29)

This programme was also discussed earlier in this chapter under 'Integrated Science'. Our interest here is its emphasis on investigations carried out by primary school children, mostly in the field and with extremely simple equipment.

The teachers' guide says explicitly:

> In order to teach science by providing many activities, a variety of materials are needed for children to manipulate and explore. Most can be scrap or used materials and need not be purchased. Many of these can be collected locally and children can help the teacher collect things needed for a particular unit. Identifying and collecting the useful materials and making equipment are themselves an important part of science learning for children.

Again, just listing the titles of the booklets written for the teachers will give some idea of the field approach used.

Titles of lower primary units: *Plants in the Classroom; Exploring the Local Community; Dry Sand; Wet Sand; Water; Cooking; Construction; Woodwork; Wheels; Arts and Crafts; Playground Equipment.*

Selected titles in middle and upper primary: *Exploring Nature; Seeds; Ask the Ant Lion; Mosquitoes; Chicks in the Classroom.*

Selected titles from the physical and chemical sciences: *Making Paints; Sinking and Floating; Making a Magnifier; Measuring Time; Moon Watchers; Stars Over Africa; Pendulums.*

The photographs in the teachers' guide to the programme are most impressive from the human and artistic points of view. One gets the feeling that the children are really doing things, enjoying and learning.

Projects stressing home experiments

The Open University of the United Kingdom

A very complete description of how the Open University operates was written by A. R. Kaye and M. J. Pentz [69]. This university, originally conceived as a 'university of the air', but more correctly known now as 'the university of the second chance' sends a complete kit of materials for home experiments to each student enrolled in certain science and technology courses. These are sent out on loan because they contain some expensive equipment. This may include, depending on the course in question, a colorimeter, a microscope (which has won design awards), a tachistoscope, a noise-meter, a binary computing device and cathode-ray oscilloscope. (It is proposed to include a laser in the optics course kit planned for 1977.) The student pays a returnable deposit for their use.

In 1972 the returnable deposit for a home experiment kit for a full course was £10.00 (about U.S.$25) which was either returned to the student at the end of the course or applied to future tuition costs. The actual retail cost of the materials was probably closer to £100, making it possible to send the student some of the expensive pieces

already mentioned which he would certainly not normally find around the house.

Part of the task of course teams has been to invent special pieces of equipment and have them mass produced. In some cases, it has required adaptation of existing equipment to reduce its complexity, sophistication, size and price.

We must keep in mind that the planning of courses and the corresponding student activities at the Open University lean heavily on the concept of systems analysis and educational technology discussed elsewhere. The role of the laboratory in science courses has been carefully weighed along with other factors and, recognizing that doing experiments at home may present serious handicaps for lack of space and time and due to personal study habits, an attempt has been made to supplement the home experience in several ways. One is to require attendance at a one-week summer school which, in the case of science courses, is devoted almost exclusively to experimental work in the laboratory of an associated university. This experience in a real laboratory containing all the necessary equipment gives the student a taste of academic practical work he has otherwise missed. In some cases he performs with professional equipment a more sophisticated or precise version of an experiment for which he was prepared by doing a simpler corresponding or related home experiment.

The television programmes which the student views throughout the year contain demonstration experiments to supplement the student's practical experience. The student also attends a study centre where a tutor may help him over some difficult points connected with either the interpretation or actual performance of his home experiment or of the demonstration experiments he has seen (but perhaps not understood) on television. At the study centre the student may also have access to a computer terminal which can be used in a calculating mode and, in time, may also be used in a computer-learning mode, capable of leading the student on by questions to which he must respond in order to progress.

The computer may also be used as a simulator of experiments in which the parameters of a given experiment can be changed at will by the student to obtain a numerical or, in some cases, a graphical read-out, describing the result of the simulated experiment.

I have taken the trouble to explain at some length the activities, available to the student at the Open University, which complement or supplement the practical experience which he will gain from his home experiments, because the student is at some disadvantage by not being able to work in a laboratory except during the summer school.

The tools of assessment have not been refined sufficiently, nor has there yet been enough experience to determine the over-all effectiveness of the home experiment activities enriched by all these supplementary devices as compared with the standard university laboratory experience, but there are indications that the diligent home

experimenter is not at too great a disadvantage if he works conscientiously with the complete package of learning materials available to him.

A clearer idea of what is typically sent to a student may be gained by noting that the kit for the Science Foundation Course (which, as we pointed out earlier, is an integrated first-year introductory university course covering some elements of biology, chemistry, earth sciences and physics in a unified presentation) contains over fifty chemicals and over one hundred pieces of apparatus. These include glassware, a chemical balance, the Open University McArthur microscope and the Open University Foxall colorimeter.

The list also includes a viewer for stereoscopic transparencies, a magnet, Polaroid sheets, tuning forks, a spectroscope, a compass, a folding magnifier, a stopwatch and atom models. The complete kit may be purchased from the Marketing Division for private use at £150.

As an example of how television is linked with experiments I shall quote from a statement on the Science Foundation Course by Dean Michael Pentz:

For example, Unit 2 deals with the concept of scientific instrumentation as extensions of man's senses, for instance to observe things that are very small or that exist for only a very short time. In the television programme, the lifetime of a muon—an elementary particle with a 'half-life' of about 1½ microseconds—is measured, by a method involving the cathode-ray oscilloscope.

The students are supplied with photographs of the oscilloscope traces they have seen during this experiment, and they make measurements on these photographs, calculate the muon lifetime, and send their results to their correspondence tutors for comment.

This involvement in experiments will be the hallmark of our TV programmes.

The IBECC home experiment project

The work of IBECC has come up several times (e.g. earlier in this chapter) but it is inevitable that it should be mentioned again under the topic of home kits because IBECC was really a world pioneer in this activity. The main entrepreneur in this case was Isaias Raw.

The reader is reminded that IBECC stands (in Portuguese) for Brazilian Institute for Education, Science and Culture. Its title indicates interests that parallel those of Unesco, so it should not be surprising that IBECC's activities have often supported the organization's ideals —for example, by serving as the Brazilian National Commission for Unesco—and has occasionally assisted the work of Unesco, as in the case of the physics pilot project in São Paulo in 1963.

IBECC has made many contributions to the improvement of science education in Brazil and subsequently in all of Latin America, but here we shall consider only its contribution to the home kit idea.

Some of this information is available in a FUNBEC publication entitled *An Effort to Improve Science Education in Brazil 1950–1966* (FUNBEC, Caixa Postal 2921, São Paulo).

In the early fifties Raw was already wondering how to provide the conditions for children to conduct scientific activities in their back-yards. He decided to produce small inexpensive kits with appropriate guides. In a private communication to the author, he says:

> This is how the early idea of a 'laboratory within a suitcase' that could be put away, was implemented. A wooden case was designed with stands, racks and tube holders. It was filled with glassware, alcohol burner, thermometer, chemicals, battery, which was all that was needed for a large number of experiments.
>
> I went around, looking for chemicals made locally, and I obtained a certain amount free of charge. The small shop, then used for the science club, started to make the boxes and the other parts. . . . The chemistry kit was born. It was followed later by an electricity kit, a third in biology. Finally one was made for general science.
>
> Remembering my experiences with the old pharmacy chemistry book, I decided not to supply just a book. I knew that boys would eagerly read the first pages and do a few experiments, but soon put it aside. The answer was to prolong the stimuli, and a monthly journal was designed. Each student would start his 'subscription' with issue No. 1, and continue along with each new month.
>
> Making these kits available not only raised the curiosity of the youngsters that got them, but their colleagues also became interested.

Raw claims that it was through the efforts of the kits that his group learned how to reach the teacher through the student, how to sell kits at a nominal price and yet have enough capital left over to plough it back into enlarging the kit-making enterprise, how to convince the teachers and the students that they should do experiments and how to prove that expensive chrome-plated equipment did not do the job as well as simple, inexpensive equipment.

A basic difference between the IBECC approach and that of the Open University home kit programme is that the IBECC kits were eventually mass produced and packaged for sale with the attractiveness of toys, but with the added fascination that came from the discovery of scientific knowledge. They were sold in stores where parents could buy them for children and were sold in sufficient quantity to make some money for the project and to have the indirect influences on science teaching already mentioned. The movement eventually had a more direct effect on formal education but we shall not dwell on that here.

That was in the early fifties. Now, in the early 1970s Raw says, concerning the new version of the kits:

> Science kits were essentially the first mass product of IBECC. With time, the effort in the direction of the new curricula, the production of school

equipment, and especially the high price of kits for the majority of the students, this program practically ceased to exist.

Several years ago we made several trials on dividing the kits into smaller units. Finally this took the shape of a single-concept kit—the pocket-book kit.

It looks exactly like a pocket book, and is made in regular and double size. On opening the cover one sees a small booklet, and a set of materials to use in performing experiments suggested in the booklet. The kits are planned within certain limits of size and cost (in Brazil they are produced for about half a U.S. dollar).

This became a mass-produced item and new kits can be planned in large numbers. Our one limitation was capital for the production of new units. In about two years production grew tremendously and kits were produced in a special section of the shop.

The kits now being mass produced and sold in various stores cover such topics as: compasses; electric circuits; electromagnets; motors; batteries; generators; electrostatistics; computers; mendel and the hybridization of plants; biochemistry of genes; human heredity; vegetable hormones; fuel cells; microscopes; polarization; rainbows; acids and bases; osmotic gardens. Most of those kits are being used as toys or are given as presents so that thousands of youngsters are carrying out experiments, guided by the booklets.

Some factors affecting the learning of science in young children

In terms of the future, how young children learn science is probably one of the most important topics in this book. It is conceivable that some of the dramatic improvements in the teaching of science will come from a better understanding of the learning process in general and, in particular, of the factors that affect the learning of science and mathematics in young children. The purpose of this section is to point out some of these factors and to give some idea of the kind of research that has been done or needs to be done in this area.

By now the reader is aware that the objectives for children learning science go, as I see it, far beyond simply learning facts about science The broad aim of learning science is the developing of an inquiring mind and a scientific approach to problems. The kinds of actions which prove that a child has developed an inquiring mind include: posing questions and devising experiments or investigations

that answer them; acquiring and applying knowledge and manipulative skills; communicating; interpreting findings critically; appreciating patterns and relationships; developing interests, attitudes and aesthetic awareness; observing, exploring and ordering observations; developing concepts.

The investigator who has probably had the greatest influence as regards learning in young children is Jean Piaget. In a recent bibliography on the development of science and mathematics concepts in children [94] 17 out of 114 entries dealt with his work and 7 of them were authored or co-authored by him. It happens, incidentally, that the work of Piaget [95] deals mostly with developing concepts. Obviously research of comparable importance still needs to be done in the other areas.

One of the earliest working papers commissioned by the United Nations Advisory Committee on the Application of Science and Technology to Development (ACAST) was entitled *The Learning Process and the Teaching of Science and Mathematics in Developing Countries* [1] by L. J. Lewis and collaborators. It is significant, however, that one of its sections was entitled 'The Learning Process in Young Children'. It identified research which needs to be done.

Since then research into the factors that affect learning in young children has made some progress, but, if I am not mistaken, it has not moved fast enough to keep up with the more empirical approaches that have otherwise characterized the reform movement in science education.

I am persuaded, nevertheless, that the learning process is an area that deserves priority action. I have not been personally involved in it as I have in other areas of science teaching improvement, but I have come to conclusions of my own as to what are some of the important factors that affect the learning of science and mathematics in young children. I propose, as a concerned amateur if you like, to list them, make a few comments about them and indicate where further information can be found. I will also mention some recent activities of Unesco and other organizations in this field.

We all know that children are much better than adults at learning some things. Children learn foreign languages with surprising ease, as parents in the diplomatic corps have discovered. Children in a foreign country, by simply playing with the native children, come home speaking the new language much faster than their parents who are often struggling to learn in formal language courses.

We also know that children have a natural curiosity about things which, if permitted to guide their exploration, could result in investigative activities similar to those of scientists. We have stressed the need for curiosity as the basis of scientific exploration. Children seem to be born with it.

The 'longing to know and understand' and the 'questioning of all things' which we cited earlier as basic elements in the spirit of

science are potentially present in children. What then are the external factors in home, school and society in general that determine the child's ability to learn science? What other built-in physiological and developmental factors are also involved? These are the questions that concern us here. One way to classify the factors that affect learning is by dividing them into extrinsic and intrinsic. This seems neat and logical, but in fact the divisions occasionally overlap.

Extrinsic factors

Heredity

Some physical and mental characteristics are inherited. A person's health, size and skin colour, for example, are strongly influenced by heredity. His senses of sight, hearing and touch are inherited and, perhaps, along with them the ability to learn certain things including manual skills, music, artistic expression and science. The potential for physical and mental growth is probably also inherited, but the child's actual development is in addition strongly affected by environmental factors.

Environment

Given a set of hereditary characteristics it is also apparent that environmental conditions can affect the way in which a child develops and, for example, what the child learns and the rate at which he learns it.

A child is born in an economic environment which greatly affects the rate at which he can learn. In the rich countries he has a better chance of being well fed and hence of developing a sound body and possibly an optimistic outlook on life. In the poor countries it has already been shown that in extreme cases some children grow up with a protein deficiency which impairs the proper functioning of the brain.

A rich child is surrounded by things and experiences which make it easier for him to learn the concepts and approaches of science. His ability to visualize colours, forms and spatial relations must in some way be related to the rich experiences that his physical environment provides for him. This enriched physical environment includes foods in sufficient variety to ensure the fulfilment of endowed hereditary propensities.

A child is also born into a social environment—obviously affected by the economic environment—which may be rich in cultural values that can help in the learning process. Especially valuable is language which permits the child to conceptualize and communicate, both of which are important in learning the concepts of science.

The technological environment also teaches a child in a devel-

oped country how to see and manipulate things, including toys and tools, which can enrich his background and be an aid in learning science.

Finally, the child is immersed in a value system associated with moral or religious rules which may help or hinder in the pursuit of scientific knowledge. Religious upbringing is sometimes associated with taboos which have, in the distant past, served a useful social function. But since one of the tenets of science is to 'question all things' it may conflict with the rules the child was taught never to question. He may grow up learning many of the facts of science (and even earn a degree in science!) but never allow himself to practise some of the processes of science or theorize along lines which go counter to the taboos of his religious upbringing. This, incidentally, can happen in both developed and developing countries.

Intrinsic factors

By these I mean those that relate to the individual himself rather than to the forces that are imposed upon him by heredity and environment (I realize that some behaviourists would question whether there are any such intrinsic factors at all).

Similarities

Although individuals differ from one another widely in certain respects, they are very similar to one another in others. It is known, for example, that the rate at which an individual grows physically and possibly also in knowledge and skills is much greater in childhood than at any other time in his life. Benjamin Bloom has indicated that as much development takes place in the first four years as in the next thirteen [96]. This has obvious implications for learning in general.

Possibly the most interesting and important discoveries that relate to the learning of scientific concepts are those of Piaget and his followers. Piaget has performed experiments with children and recorded results which indicate that children are capable of doing and learning certain things associated with scientific concept learning at certain stages in their physical development. They seem to be capable of forming concepts related to space, time, matter, motion and conservation in a definite chronological order. His experiments have been repeated in different parts of the world and have confirmed his basic conclusions. These obviously have great relevance to what concepts children can learn and when they are ready to learn them.

B. F. Skinner has also found other kinds of similarities and these pertain to operant conditioning which we mentioned earlier. Certain behaviour patterns of children (and adults) can be changed by the

principle of reinforcement. In other words, certain kinds of learning (I suppose Skinner would say all kinds) can be effected by the techniques of operant conditioning.

Differences

But today we are also aware that there are important individual differences among children and there is a tendency toward individualized instructional practices. We are aware that curiosity and creativity are characteristics that assist in the learning of science but not enough research has been done to enable us to assert that these can be stimulated or induced.

We know that motivation and stimulation play important roles in learning but research is needed to know just how to use them in the teaching-learning strategy. We also know that children differ in the rate at which they learn, in their attention spans and in their tendency towards boredom but we do not know the basic causes nor the proper steps to take to compensate for these differences.

Finally, we know that the attitude of the student is important. He may have an attitude that assumes that there is nothing he himself can do to take matters under his own control, or he may believe that his active intervention can change the outcome of the future. Mary Budd Rowe [97] has proposed that the proper teaching of science emphasizing the reproducibility of experiments and the concepts of probability and limits of error may influence the student's attitude toward life even outside the science classroom.

We have listed very briefly many of the factors that affect the learning of science in children. At this point we could try to select a few of them for more detailed discussion, but to do justice even to, say, the experiments and conclusions of Piaget, would go beyond my own present knowledge of the subject so I have decided instead to mention some projects in which many of the factors above have been considered at length. The publications of these projects usually include rather extensive bibliographies and I will refer the reader to them rather than attempt to give them here.

Unesco activities

Although there are other ways to be introduced to the literature of learning of science in children, my own experience has come through my association with Unesco so I shall mention some Unesco activities, the publications of which could lead the interested reader to the necessary bibliographical references.

Asian Expert Seminar on the Development of Science and Mathematics Concepts in Children

This was the title of a seminar convened by Unesco and Unicef in association with CEDO. Its report (1972) is available from the Unesco Regional Office for Education in Asia, Bangkok (Thailand).

The titles of the chapters indicate the themes discussed at the conference. They also suggest where to look for an elucidation of several of the factors that affect learning which we mentioned above. The titles are: 'Information on the Process of Learning by Children'; 'Some Aspects of Understanding Visual Symbols'; 'Implications for Curriculum Development and Teacher Education'; 'Analysis of Country Reports'; 'Guidelines for Research'; 'Recommendations'. The appendixes include: 'Notes on Concepts and Concept Learning'; 'Research Methodology and Interviews with Children at the Seminar' and a bibliography of forty-eight particularly recommended and ninety-six recommended references. The well-known names of Ausubel, Beard, Bruner, Lovell and Piaget appear here, of course, but the total of more than 120 others can lead the interested reader to topics, often expansions of those of pioneers like Piaget, related to the field.

Seminar on the Development of Science and Mathematics Concepts in Young Children in African Countries

This seminar was in progress in Nairobi while the present work was being written so its report was not yet available. The twenty or so participants were closely associated with Unesco/Unicef-supported projects in Botswana, Ethiopia, Kenya, Lesotho, Malawi, Mauritius, Somalia, Swaziland, Uganda, United Republic of Tanzania and Zambia.

One of the working paper titles was: *Piaget and Africa—A Survey of Research Involving Conservation and Classification in Africa* by R. O. Ohuche and R. E. Pearson in which they say:

> Investigators have been particularly interested to test in different populations his [Piaget's] proposal that children's thoughts develop through definite sequences of stages, each of which has its own characteristics.

I mention this one in particular because it would indicate the far-reaching impact that the studies of Piaget have had world-wide. Other topics ran more or less parallel to those of the Asian conference, indicating that Unesco is picking up a great deal of information through country reports on how children learn science, especially in developing countries—one of the constant concerns of this book. A bibliography on the development of science and mathematics concepts in children in African countries was compiled and should be available in the final report.

Symposium on Interactions between Linguistics and Mathematical Education

This Unesco symposium was held in Nairobi (Kenya) from 1 to 11 September 1974. The importance of language as a factor in learning briefly mentioned earlier becomes here the focal point—applied to mathematics education. I have chosen the titles of only two of the papers to give the flavour of the symposium: *What is Linguistics and How may it Help the Mathematics Teacher?* This includes an annotated bibliography. Another is: *Linguistics Problems Encountered by Contemporary Curriculum Development Projects in Mathematics*, including references. Scanning it briefly I was struck by the following sentence which seems to indicate that the processes used in elementary physics are also considered relevant to the learning of mathematics by children:

> ... the view taken here is that measuring and weighing, counting and classifying are not only activities appropriate to early lessons in mathematics but ones which are essential, both as pre-requisites to the development of the abstract concepts with which mathematics is also concerned, and as providing the ingredients of a fertile soil in which language can grow in use and in meaning.

The report of the symposium will, of course, be available from Unesco.

Other projects

Space does not permit giving details here so let me refer the reader once again to the *Eighth Report of the International Clearinghouse on Science and Mathematics Curricular Developments, 1972* [24]. There are twelve projects listed outside the United States and fifteen projects inside the United States in the elementary science category. There are thirty-eight mathematics projects outside the United States and thirty-three in the United States (without specifying level). There is obviously a wealth of information to be obtained by writing to the directors of these projects for information.

I should like to conclude by citing just one reference which impressed me—a non-specialist in this field—as a clear exposition of what distinguishes some of the modern views of learning from the old. It is 'Some New Views of Learning and Instruction' by Robert M. Gagné, in the May 1970 issue of *Phi Delta Kappa*. He addressed himself to three questions: (a) For student learning to be most effective, how should the learning task be presented? That is, how should it be communicated to the student? (b) When the student undertakes a learning task, what kinds of activity should be encouraged? (c) What provisions must be made to ensure that what is learned is remembered and is usable in further learning and problem solving?

These are questions that transcend the learning of science and mathematics but the reader who is stimulated by these questions will find a good discussion in this reference.

Gagné says:

> My purpose here is to outline some . . . changes in the conceptions of human learning and memory and to show what implication they may have for the design and practice of instruction. I emphasize that I am not proposing a new theory; I am simply speculating on what seems to me to be the direction in which learning theory is heading.

I found his views provocative.

Part III
Strategies for the future

7

Some possible strategies for change

How do you generate and encourage innovation?

It has been a demanding task, which this one-man effort has only imperfectly fulfilled, to consider, on a world-wide scale, past experiences and present trends in science education reform. And now we embark on the most difficult part of our journey—to propose strategies for the future. We shall, in this final part, attempt to answer the questions: 'How do we propose to get there?' and 'What does it take?'

We have already discussed, in Chapter 4, what innovation is and how it is generated. Our problem now is to suggest, in particular, how further innovation in science education can be encouraged and how to go about achieving the reforms that are still needed. Our judgement will be based on answers—already given—to the questions raised in Chapter 4: 'What went wrong?' and 'What worked well?'

A systematic assessment of the entire movement has, unfortunately, not been performed. The obvious first suggestion for planning future reform is, therefore, that some international organization, perhaps Unesco, should study the experiences in science education reform over recent years in a more thorough way and with greater resources than were available to this writer.

Ingenuity will, no doubt, continue to be needed for future innovations but it would be foolish to embark on new programmes without the benefit of past experiences. It is well known that some of the early efforts, such as the introduction of the so-called 'new math', for example, have recently come under fire and generated corrective measures.

Perhaps a commitment to a systems approach would be one way to avoid the random nature of some of the previous approaches.

This would require a well-funded team effort. In the meantime, the synoptic view in this book may offer some suggestions for action.

The enthusiasm for reform which was so apparent in the 1950s has been dampened. A certain amount of disillusionment has set in. The urgency does not seem as great. Certainly the social and educational climate of the seventies is different from that of the fifties and sixties.

We are naturally led to ask if there is still need for innovation and reform in science education. There is every indication that science and technology will play increasingly important roles in our lives in both advanced and developing countries. Hence I believe there is a continuing need for improvement in the way science is taught both to produce the scientists and technologists of the future and, possibly more important, to endow non-scientists with the advantages of an inquiring mind and an awareness of the power and limitations of science.

The focus of global concern has shifted from the cold war atmosphere of the fifties in which the military needs for technology supplied some, though not all, of the motivation for educational reforms in science education, to the search for détente which has, in the seventies, to some degree replaced dependence on deterrence.

The new global crises centre around human survival as we have become increasingly aware of the earth's limitations in natural resources and the environmental effects of the misuse of those resources. We are beginning to recognize that overpopulation aggravates all the other problems, especially those of food and employment.

Science and technology will certainly be needed to solve these problems. We continue to celebrate centenary anniversaries of national independence, when they occur, but we are also suddenly becoming aware of global human interdependence.

Where, then, do we go from here in our science education reform?

Local strategies

We can begin with the individual science teacher. He can keep himself better informed now than ever before and try new approaches to teaching in as far as both the quantity and the quality of journals devoted to improvement of the teaching of science have increased in the past decade.

Admittedly, this puts a very heavy burden on the shoulders of teachers in certain regions of the developing world and in the less developed areas of the advanced countries but it is not an impossible task. I make a plea, therefore, that the individual teacher feel a responsibility for improvement. He need not wait for help from the outside. He can take some initiative by himself.

Science education improvement can also be promoted at the

local school board level. If the board includes a scientist or a science educator with a concern for innovation, all the better. Most of the members will usually not be scientists, however, so the possibility of change really depends on the appreciation which non-scientists have of the future role of science and technology.

At the county and state levels the decision to create special centres for research in science education, special science museums and exploratoriums is often in the hands of county and state boards of education. These should, therefore, include scientists and science educators.

Some states within a country are so large that the educational systems are as complex as those of an entire country. The state of California in the United States, the state of São Paulo in Brazil, and some of the states in India are examples of this. Inspired leadership in the state boards of education or the prodding of concerned scientists attached to them have promoted significant improvements in science education in all of these cases.

The autonomy usually possessed by universities gives them a particular advantage in taking the initiative for reform. Science teaching centres have sprung up through such university initiatives in many countries (e.g. Thailand, Israel, Venezuela and the Philippines).

In all cases, the local strategy for reform can be greatly affected by the initiatives of individual scientists within the existing organizations if they are devoted to the concept of continuous reform and innovation in teaching. Such dedicated individuals have played an important role.

National strategies

Non-governmental

Long before the start of the reform movement in the fifties, teachers' associations in the separate scientific disciplines were active in different countries. Very recently information on the work of these associations has been gathered by the newly formed International Council of Associations for Science Education (ICASE) which will be discussed later under global strategies.

To illustrate briefly the work of these associations I have chosen the one of which I have been a member for many years, the American Association of Physics Teachers (AAPT), but I have chosen it merely as the example I know best. The characteristics of the AAPT which I shall describe are also exemplified in some form or another by organizations in many countries devoted to such fields as chemistry, biology, mathematics and the earth sciences. For detailed information of organizations in these areas as well as in integrated science, the reader is referred to the publications of ICASE.

The American Association of Physics Teachers began in 1930 with forty-two members. By 1969 it had a membership of 13,000, consisting of college and university teachers, high school physics teachers, scientists in industrial laboratories and others interested in promoting and supporting its objective of advancing the teaching of physics and furthering the role of physics in our culture.

Some of the aims of the AAPT are accomplished through the publication of two journals: the *American Journal of Physics,* devoted primarily to the college level, and *The Physics Teacher,* designed primarily to meet the needs of high school teachers.

Other important activities include national and regional meetings at which individual teachers are encouraged to participate by presenting 10-minute papers describing approaches, methods, techniques or materials they have developed for the improvement of teaching-learning strategies. These are supplemented by longer papers prepared by specialists in some field of physics teaching or research. Another type of action is the work of special committees such as the Committee on Apparatus, the Committee for Educational Institutions, the Committee on High School Awards, the Committee on Instructional Media (formerly the Committee on Visual Aids) and the Committee on International Education in Physics.

A special commission was created in 1960 with financial support from the National Science Foundation (NSF) to improve physics curricula in universities, colleges and high schools throughout the United States. This was part of the broad strategy of NSF during the early years of the science education reform movement. This commission was phased out in 1967 with the understanding that many of its activities would become the responsibility of AAPT. Important contributions to the improvement of physics teaching have been made by several books sponsored by AAPT devoted to new ideas and demonstrations for lectures and for experiments in the laboratory.

An interesting account of the organization, history and activities of AAPT is given in its 1970 directory of members.[1]

Besides teachers' associations devoted to a single discipline there are some, like the National Science Teachers Association (NSTA) of the United States devoted more broadly to science education as a whole. In the United Kingdom, the Science Masters Association has had a strong influence in science teaching improvement. Its journal has sections devoted to the individual sciences as well as to interdisciplinary problems.

1. *The American Association of Physics Teachers—Organization and Activities, History, Constitution and Bylaws and Directory of Members as of 1969,* published by American Association of Physics Teachers, 335 East 45th Street, New York, N.Y. 10017.

This random and very incomplete sample of existing non-governmental associations of science teachers may serve to give at least a flavour of their activities. They have, incidentally, had great impact on science teaching round the world.

Governmental strategies

Two strategies for governmental assistance to reform of science education emerge from recent experience. One is the establishment of permanent institutions devoted to innovation and reform, and the other is government support of special improvement projects.

Permanent institutions devoted to reform in science education. Examples of the trend toward the establishment of such institutions were given in Chapter 5. The actual institutions vary from country to country. In the countries of Eastern Europe, for example, they may be pedagogical institutes set up under the guidance of the Academy of Pedagogical Sciences. Elsewhere they are closely connected with universities but not necessarily part of an existing department of science education. This is the case for the Unesco-stimulated National Science Teaching Centres in Israel and Thailand.

Government support is less direct in the case of institutions like the Centre for Science Education of Chelsea College, London, the Institute for Educational Technology of the University of Surrey in Guildford and the Institut für die Pädagogik der Naturwissenschaften in Kiel. In the Lawrence Hall of Science of the University of California and in the Science Teaching Center of the University of Maryland, both in the United States, it filters down in the form of grants for projects conducted by these centres or financial assistance from the state body responsible for university education.

A permanent institution specializing in science education is usually an expensive enterprise large enough to necessitate government funding, except in the most affluent countries.

Government sponsorship of improvement projects. The other strategy that was exemplified from the start of the reform movement was that of government support for isolated projects begun by non-governmental groups. These were discussed in Chapter 4. The early 'big five' projects in the United States—PSSC, BSCS, CHEMS, CBA and SMSG—and, of course, many others that followed, received substantial support from the National Science Foundation.

Sometimes a department within a university is given government support for a project in science education because of a special national need. A case in point is the Centre for Advanced Studies of the Instituto Politecnico Nacional in Mexico which contains a group devoted to the writing of a set of new books in science for Grades I to VI. A unique feature of this project is that the output consists

of very well illustrated books for free distribution throughout Mexico. It is part of a larger project that includes subjects other than science. Many millions of copies of these books have been distributed.

The purpose here is not to give more examples, since quite a few have already been given, but simply to point out the need for government support if a project is to have national impact.

How does government support get started? Government, ideally, is an expression of the will of the people. Innovation, however, does not usually begin with a group decision. As we said in Chapter 4, where we discussed the nature of innovation, it usually takes an individual acting as an entrepreneur to raise the consciousness of larger groups of people so that the need is felt for reform in science education.

Government support does not come spontaneously. Appeals and specific proposals for action have to begin with concerned individuals who generate a following large enough to make an impact on the government.

We could have asked a similar question about programmes for medical care, population research or space. All require government support. None would have started without the efforts of concerned individuals.

Regional and international strategies

There are situations in which concerted action by a group of countries in the realm of science education improvement can bolster the efforts of the individual countries. These activities sometimes occur within a single region and the governing body is called a regional organization. An example would be the Organization of America States (OAS) which comprises many of the countries of the western hemisphere, the great majority of them being in South America. There are analogous organizations in other parts of the world.

The interests that bind countries in regional or multinational activities are obviously political, economic, social, scientific, cultural and educational or a mixture of these and other concerns. The Organization for Economic Co-operation and Development (OECD), for example, has an economic focus. It is multinational but not regional since it now has a number of non-European members among its twenty-four members, most of which are European. CERN (European Organization for Nuclear Research), on the other hands, as its title indicates, is a regional organization with a scientific concern. Both OECD and CERN, incidentally, have some interest in science education but it is peripheral to their main concerns. The examples I have given have, unfortunately, been limited to the Western world, which I know best. I am not deliberately excluding

Eastern Europe where similar organizations no doubt exist. The logical distinctions I have made as to different types and functions must be applicable to them as well.

The types of actions which are appropriate to international and regional action include seminars, symposia, conferences, workshops, regional pilot projects and science teachers' associations. The latter have been particularly productive in Africa where there exist, for example, both a West African and an East African Science Teachers' Association. Regional activities of this kind exist also in the Caribbean and in the Australian areas.

In order to keep this section reasonably brief I shall not attempt to give an exhaustive survey of the regional strategies employed round the world. Instead, I will refer at length, below, to the report of a regional seminar on the teaching of science in Latin America because it has a section entitled 'Modes of Action' which contains, in effect, model strategies for regional action adaptable, in my opinion, to all regions of the world.

It is important to note that the new concerns in science education have often been brought to the attention of national groups at regional and multinational conferences and symposia. Recent examples of these concerns are integrated science, the training of teachers for integrated science and the role of science education in the study of national resources and the environment, all of which have been topics in international conferences, workshops and symposia.

Who takes the initiative in generating regional and international modes of action? It could be a national group seeking affiliation with other national groups. This has occurred with science teachers' associations. It could, of course, be an existing local group with an interest in science education. But sometimes the initiative comes from an international organization such as Unesco which has sponsored many regional activities or the International Council of Scientific Unions (ICSU) which more recently has been involved in similar activities. The initiative can, of course, also come from a concerned individual in a given country who acts as the entrepreneur whose activities eventually spark international collaboration. The individuals who started the science curriculum reform in the fifties belong in this category. In short, innovation leading to regional activity can start at many different levels and should be encouraged to do so.

Unesco is in a class by itself because it is the Specialized Agency of the United Nations with competence and responsibility both in science and education and because it has always had a special concern for the developing countries. The developing regions of the world, in Unesco parlance, are Asia, Africa, Latin America and the Arab States. These subdivisions are artificial in the case of some countries; for example, many of the Arab States are to be found in Africa. Unesco's subdivisions are really regional groups composed of countries whose common interests and often, but not exclusively, their

geographical proximity, makes them administratively a homogeneous group.

In any case, Unesco has established regional offices for education and regional offices for science in Asia, Africa, Latin America and the Arab States. Many regional activities to improve science education have arisen out of, or with the help of, these offices.

The Unesco pilot projects [34], [84], [85] in physics, chemistry, biology and mathematics were regional projects which began in Latin America, Asia, Africa and the Arab States respectively. Follow-up activities for a given subject have been carried out first in the initial region and, to a certain extent, have expanded into other regions. Activities in integrated science have begun in each of the several regions.

I have chosen to list below the 'modes of action' or strategies for the implementation of science education improvement which arose out of discussions at a Unesco regional seminar on the improvement of science education in Latin America held in Montevideo during December 1972 because the ideas are applicable to all the regions. Since the work of the regional seminar itself is an example of a viable strategy, I begin by summarizing how it worked.

Montevideo is the seat of the Regional Unesco Office for Science in Latin America but the programme of the seminar and the details of its organization were planned by that Office in conjunction with the Regional Unesco Office for Education in Latin America and with the Division of Pre-University Science and Technology Education of Unesco. Seminars of this type have been held by Unesco in other regions as well.

The specific objectives of the Montevideo seminar were:

1. To exchange information among the participants on:
   (a) the present situation regarding science education in Latin America;
   (b) the characteristics of specific activities already under way for improving science education in the region, and results obtained so far;
   (c) the nature, scope and results of the recent most important projects world-wide for the improvement of science education;
   (d) resources available in the region for further efforts towards the improvement of science education at the national and regional levels.
2. To exchange ideas among the participants on:
   (a) the nature of the process of innovating in science education, and the experience gained in this matter in different countries;
   (b) educational problems which are specific to each of the various disciplines (mathematics, biology, integrated science, etc.);

(c) educational problems of a more general kind which affect the teaching of all scientific disciplines (e.g. pre-service and in-service training of teachers, design and production of low-cost science teaching equipment, extracurricular science activities, etc.).

3. To develop guidelines for a plan of action towards the improvement of science education in the region, including suggestions for future activities that could be carried out by science teachers, by national institutions and authorities, by regional bodies, and by Unesco and other international organizations.

The participants were selected from among persons actively engaged in the region in the improvement of science education in its various aspects. The seminar was attended by participants from the following countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay and Venezuela.

In accordance with the objectives of the seminar, two types of working groups were formed: one set was composed by groups studying problems specific to each scientific discipline (the groups A.1, A.2, etc., mentioned below); the other set included groups treating educational problems common to the teaching of all disciplines (the groups B.1, B.2, etc.).

Those two sets of groups functioned with a high degree of flexibility. To the groups envisaged from the beginning, new ones could be added according to the interest expressed by the participants during the work of the seminar. Thus, a group on environmental science was added to set A.

The complete list of the two sets of working groups is as follows:

A.1	Mathematics	B.1	Pre-service and in-service training of teachers
A.2	Physics	B.2	Educational technology
A.3	Chemistry	B.3	Design and experimentation of new courses
A.4	Biology	B.4	Design and production of low-cost laboratory equipment
A.5	Environmental science	B.5	Objectives and evaluation
A.6	Integrated science	B.6	Extracurricular science activities

The participants worked during four sessions (of half a day each) distributed among the working groups of set A. During four other half-day sessions they re-distributed themselves among the various working groups of set B.

The discussions that took place within these working groups made it possible, first of all, to identify the problems and some possible solutions; they then led to a number of concrete suggestions

for strategies which could make it possible to implement these solutions. The working groups functioned as information, discussion, and drafting groups, each of them led by a co-ordinator. Their results were presented in the form of successive progress reports to the whole seminar and discussed in plenary sessions.

The interested reader is referred to the final report (in Spanish) of this seminar entitled *La Enseñanza de las Ciencias en América Latina* [88]. An English version of Chapter I of that report containing a complete Table of Contents is also available. The next section is essentially a condensed version of Chapter IV of that report entitled 'Modes of Action'. It may seem slightly out of context here because the previous chapters which analysed the problems of science education in the region are not included. These problems have, however, been treated rather generally in previous chapters of this book. What follows, therefore, are eight recommendations for modes of action proposed by the participants at the Montevideo seminar, but which, as observed earlier, are probably valid world-wide.

Recommended modes of action

Creation of working groups for the improvement of science teaching and support for those which already exist

A working group, as the name implies, consists of a team of people who work at the solution of one or more specific problems related to science teaching improvement over a sustained period of time which may be as long as a year or more. Ideally, a team would contain scientists, educators, practising teachers, designers and specialists in the arts of communication and information. In practice, however, the team members are mostly teachers who acquired a measure of expertise in some of these branches.

The results of their labours consist of tangible outputs in the form of materials such as publications, laboratory equipment, guides for teachers and pupils, scripts for television programmes, films and other audio and visual materials. The Unesco pilot projects for the teaching of the basic sciences and mathematics demonstrated the basic capability of working groups—namely that a team of teachers from a region can resolve their own problems and produce their own curricula.

The formation of working groups can be sponsored by groups of teachers and scientists either working alone or with support from national authorities. Sponsorship by an international agency, such as

Unesco or a regional body like the Organization of American States, can often give the financial support and prestige necessary to initiate activities which eventually have to be self-sustaining or government supported. The support of a host institution such as a university can also be an asset.

From what we have said it is clear that the success of a working group can be measured by its output of materials including the publications that give their experiences the widest possible dissemination within the country and eventually within the region and beyond.

Organization of workshop seminars

Characteristics

A workshop seminar is an interdisciplinary group that exhibits both the characteristics of a seminar—exposition and interchange of ideas, experiences and research—and the activities of a workshop in which the participants produce materials for teaching science such as textbooks, laboratory and other equipment for experiments, audio-visual materials, development of examination and objective tests or invention of problems, etc.

It is important that it operate neither solely as a seminar (in which materials are not produced) nor solely as a workshop (devoted uniquely to production without spending time on design and development of prototypes).

The aim of a workshop seminar is to bring together a body of participants similar to that of a working group to work during a limited period of time, possibly as short as a few weeks, on a predetermined theme or activity in a chosen area of science education.

Objectives

To permit teachers to learn about teaching by confronting them with the real problems of teaching and the search for realistic solutions. In the process they may also contribute to the development of curricula adapted to the specific needs of their country and their region.

Structure and method of operation

It should last between three and six weeks, as the situation demands, and should have between fifteen and thirty participants on the average.

During the workshop seminar, participants exchange ideas and experiences related to science education and produce science teaching materials. They will take these back home with them to test on their own students and will share their experiences with their colleagues.

The work of the participants will be guided by specialists from

the region who have proven their ability in some area of science education, some consultants in educational technology, and professors from the universities and teacher training colleges.

Some of the participants may obtain fellowships and remain to work in the headquarters of the workshop seminar for a period that might last from a few months to a year.

The theme of the work may be very specific as, for example, preparation of questions, problems and tests for evaluation for a chemistry course and the comparison of these with the objectives of the course. In this regard, see the report of Eric Rogers on the workshop seminar which he led in Montevideo in 1971, entitled *Improving Physics Education through the Construction and Discussion of Various Types of Tests* [80]. Or the theme might be much broader, such as the design of part of a mathematics curriculum based on the concept of probability.

Organization and running of a workshop seminar

One method is to start with working groups that already exist in the country. Out of their experience guidelines for the creation of future workshop seminars can be developed.

It would be useful to select participants who understand clearly the objectives of the workshop seminar and who will dedicate themselves to continue working on the problems generated even after it has finished.

Multiplier effect of a workshop seminar

As mentioned earlier, at the end of the workshop seminar each participant will take with him the prototype materials that were developed for the express purpose of carrying out the charge which they accepted, namely to continue to test their materials in their own teaching and make them known to their colleagues. To this end it would be useful to require participants to write a report of the activities they carry out when they return to their homes.

Activities of working groups and workshop seminars

The design of modular units

Although the design of a complete curriculum for a course is difficult and time consuming, a contribution toward this end is the design of mini-curriculums or modular units. These are parts of a curriculum devoted to a limited theme the development of which, however, can give the participants experience in handling all of the variables that enter into the development of an entire curriculum. Instead of devel-

oping a whole course in physics, for example, they could generate a modular unit on electricity and magnetism.

Because they cover only a limited portion of the whole curriculum, these modular units are relatively easy to test on students and to modify for the purpose of improvement. The educational authorities may, perhaps, be more easily persuaded to permit the testing of a modular unit or two than to contemplate a complete change of curriculum.

By means of exposure to modular units it should be possible to have all the teachers of a country have some experience with new methods and materials, thus making their eventual acceptance on a national scale more likely.

Supporting services—production, distribution and maintenance of materials and equipment

Although the main job of the participants of the workshop seminar is not to mass-produce materials but to work on problems of design, prototype development and testing of materials, they should, if possible, promote, through proper channels, their adoption on a large scale.

We refer the interested reader to the Montevideo report [88] for details of this very important aspect of the work. Particular attention is given to the problem of maintenance and repair of equipment and the possibility of training workshop seminar participants to cope with this problem themselves.

At the same time we would emphasize the possibility of using low-cost materials that were not specifically designed for science teaching but which, because of their availability and low cost, could be adapted for this purpose with a little imagination.

Pre-service and in-service training of science teachers

All the activities of working groups and workshop seminars may be structured to emphasize their teacher-education aspect. In fact, since teachers tend to teach the way they were taught, if they could all have a workshop seminar experience, it might contribute a new dimension to their conception of what new and more effective methods and materials exist for science teaching in as far as they themselves were instrumental in the design.

Exchange of information

A classic and most important action for science teaching improvement is, of course, the exchange of information.

The problems related to the production and dissemination of publications and teaching materials are discussed at length in the Montevideo report, as well as the question of how meetings, confer-

ences and symposia at national, regional and international levels can be promoted, arranged and conducted.

Exchange of persons

Another time-proven mode of action for science teaching improvement is the interchange of personnel among groups within a country as well as within a region.

Short-term and long-term visits by specialists in various aspects of science education and by university professors can prove invaluable as stimulators of innovation and improvement.

Scholarships and fellowships can supply the incentive and the means for the younger scientists and teachers to go abroad to learn new approaches, methods and techniques. The effectiveness of this means of exchange of persons can be enhanced if the activities of the participants are well planned in advance so that the fellowship-holders learn what is most needed in their home institutions and are helped to put their new ideas into practice when they return.

Institutionalization of the process of science teaching improvement

This topic, which we have dealt with in Chapter 5, was amplified with many examples from the Latin American region. The Montevideo report documents how the formation of working groups can be used as the start of a series of many steps that lead to the formation of permanent institutions devoted to continuous improvement and reform in science education.

Emphasis was placed on the fact that many working groups started by concentrating on specific and concrete problems which they had to solve and that, in the process of working on these, their experience led them to consider broader problems of science education and in some cases to the promotion and creation of permanent centres.

An advantage of concentration on local problems is that the institution that grows out of these efforts has its feet firmly planted in the realities of life in the region.

Nevertheless, it is also possible for an institution to be developed as such by an entity of the Ministry of Education or by some other official agency. A case in point is the National Centre for the improvement of Science Teaching (CENAMEC) which has developed under the joint auspices of the Ministry of Education and the National Council of Scientific and Technological Research in Venezuela. An important characteristic of this type of centre is that it will not only permit the creation of working groups and workshop seminars such as those we have described, but will also promote their creation—in order to utilize them in its own operations.

Global strategies

If you want to improve the teaching of science globally you must utilize the mechanisms of international organizations with an interest in, and a commitment to, innovation in science education world-wide. My approach to global strategy will be based on the plans which two international organizations have in this area. One is the United Nations and its Specialized Agencies, and the other is the International Council of Scientific Unions (ICSU).

The United Nations has published its recommendations for a global strategy in its World Plan of Action for the Application of Science and Technology to Development [98], [99]. This was generated with the assistance of its Advisory Committee on the Application of Science and Technology to Development (ACAST).

ICSU, for its part, has worked for the improvement of the teaching of science through the education commissions of its unions and by creating a special Committee on the Teaching of Science (CTS) which has been working in concert with Unesco and with several other committees having a special interest in the improvement of education in science and technology.

The basic difference between the United Nations and ICSU is that the first is a governmental body. Its actions have to be an expression of a consensus among representatives of over 140 Member States. ICSU, on the other hand, is a non-governmental association of scientific organizations and academies of science from about sixty countries devoted to international collaboration in science. The seventeen unions associated with ICSU are run for and by scientists in different scientific disciplines. It has worked closely with the United Nations by providing, among other things, expert backstopping to the scientific programmes of the United Nations, in particular to those of Unesco, the Specialized Agency of the United Nations family with a special responsibility in science education, and by performing some tasks for Unesco under contract. There is also a broader and closer relationship between ICSU and Unesco which stems from the fact that ICSU has received much, although not all, of its financial support in the form of annual subventions from Unesco.

As a governmental organization, the United Nations works at the behest of, and through, the governments of its Member States. This has advantages and disadvantages. One obvious disadvantage is that working through governments can be ponderous and slow —the inertia of the system is high—but it also means that once it gets moving it can have a large momentum and provide a large impact. An advantage of the United Nations is that if, through its action, a government is stimulated to participate in science teaching

improvement activities, it has the power to implement them on a nation-wide scale. We have repeatedly pointed out that in the case of certain governments, approval and support from the Ministry of Education is essential for the success of an innovative programme in science education.

ICSU as a non-governmental body has the advantage of being able to mobilize quickly the talents of scientists from many different disciplines and countries for special global tasks. The great success of the International Geophysical Year (IGY)—probably the best known ICSU-sponsored project—is proof of this. This ability to mobilize scientists may be very important as the problems of, for example, natural resource limitations and environmental pollution—each of which has science education implications—become increasingly serious.

The World Plan of Action

The World Plan of Action (WPA) [98] is based on several premises, one of the most important of which is that '... the scientific approach offers the best hope for assisting the developing nations to speed up the process of their all-round development'.

Great stress is also placed in the WPA on the need for indigenous capacity. It says:

> ... it is tempting to argue that the best hope for developing countries lies in their acquisition of technologies that are already applied in more advanced countries, and that it is a mistake and waste of their resources for them to go in for research and technical development of their own, in view of the cost of research and development and the special difficulties encountered in developing countries. There are several reasons, however, why developing countries should not rely entirely on foreign sources of technology. It is difficult for a country that does not itself possess a certain number of trained scientific and technical personel to know what usable technology exists elsewhere, to understand it, to adapt it to the country's specific needs or peculiar conditions, to repair and maintain the necessary equipment, or indeed to operate it. If a country has built up its own scientific and technical capacity, it is in a much better position to utilize what exists elsewhere. ...

The WPA is an international development strategy for a co-operative action programme that should lead to a reduction of the technological gap between the developing countries and the rest of the world. It includes, therefore, much more than science and technology education. It consists of two parts.

Part One—prepared by the Advisory Committee itself—lists priority areas selected as being particularly important and in which science and technology can make a resounding impact. Here science

education improvement appears prominently. It also outlines the committee's proposals for the implementation and financing of the plan. Part Two consists of more detailed proposals for the future in a wider range of areas. It also contains financial projections submitted by the organizations and agencies of the United Nations system, by intergovernmental and non-governmental organizations and by a number of individual consultants.

In the area of science education, the main agency consulted was Unesco and at one time, various specialists, including myself, were asked to submit papers on science education improvement in our personal capacities as consultants [1], [2]. Later, as mentioned in the preface, a working party of experts was brought together by Unesco to make recommendations on the subject [3].

WPA—Part One

Among other priority areas mentioned in Part One—including, for example, the storage and preservation of agricultural products, control of livestock disease, human disease control and natural resources—we find a very specific area entitled 'Improvement and strengthening of science teaching in secondary schools'. It was singled out by the Advisory Committee as worthy of a concerted attack and dealt with in two special reports [3], [100]. In them are given some of the reasons why the committee concentrated on pre-university and especially secondary school years. Essentially, the committee emphasized not only the obvious point that it is from the secondary schools that the expanded supplies of university-trained scientists and technologists will have to be drawn but also the importance of infusing the great majority of secondary school leavers who do not go on to universities with an understanding of scientific approaches and a basic knowledge of the findings and potential of science and technology.

In its first special report on science education [3] the committee formulated four specific recommendations designed mainly as essential preliminaries for future strategies and addressed primarily to Unesco. They were related to (a) more intensive staff facilities to develop and disseminate new techniques and materials used in pilot projects; (b) the convening of a working party to formulate ideas and guiding principles for the forward planning of science teaching activities; (c) the creation of an international centre for science teaching development and dissemination; and (d) the wide production and circulation of publications to make teachers, scientific administrators and others concerned aware of the great advances in science education.

Additional recommendations were presented in the committee's second special report on science education [100] relating to intensified study of the learning processes in young children with special reference to science education in developing countries and to the supply and training of science teachers.

All of the Part One recommendations to Unesco have been acted upon to some degree except (c). Concerning (c), incidentally, there is still no international centre for science-teaching development and demonstration. Instead, as we have indicated earlier, several national centres have been created. Perhaps one or more of these can begin to assume some of the responsibilities of an international centre.

The recommendations made to Unesco include ideas that would be useful for national governments as they plan their own strategies for science teaching improvement. I would therefore urge educational decision makers to read the special reports [3] and [100] mentioned earlier. The global task is so formidable that it cannot be done by Unesco or by any other international agency alone.

WPA—Part Two

Although the precise term 'systems approach' is not used, it seems to me that it is the essence of Part Two of the WPA. It specifies a target population—developing countries. It specifies objectives and proposes quantitative goals. The degree to which these are fulfilled is its measure-of-effectiveness. All of this is broadly outlined in a chapter entitled 'Science and Technology Policies and Institutions', which indicates in general the role that education and training will play in the over-all science policy of a country.

It is perhaps indicative of the high priority given to science education that the second chapter following the general introduction is the one entitled 'Science and Technology Education'.

I have room here only to name the main topics of this chapter and make some brief comments. I shall omit the cost estimates because I shall have something to say about costs in Chapter 8. I would again advise educational planners to read the details in the World Plan of Action itself [98].

It begins with a review of what is wrong with existing systems of science and technology education—a subject we have already dealt with in earlier chapters. It then proceeds to make recommendations under the following headings:

National planning for science and technology education. Granting that manpower planning is a complex operation which cannot be seen simply in terms of quantitative projections, based on stated economic goals, it recommends developing countries to embark on a rigorous evaluation of all projected educational developments, particularly in the field of science teaching. It also suggests that educational strategy should to some extent reflect the relative importance, in the long and short term, of the main sources of material wealth in the country. It points out the need for reliable educational data and the need to ensure that the field of science and technology is incorporated

into the over-all educational planning process, suggesting that in practical terms this implies setting up a subsidiary body within the main policy-making body concerned with the formulation of plans and policies of science and technology education.

Analysis and design of the system of science and technology education. This programme is divided into three sections corresponding to three levels of complexity in the task of designing the science and technology education system. These are:

1. The analysis and redesign of the over-all system and the various relationships among its major parts (system design). Attention must be given to administrative and organizational relationships among the major programmes, to the boundaries between different levels and to the interaction of the system of science and technology education with the over-all educational system within which it is embedded.
2. The analysis and redesign of the specific courses and programmes in the various disciplines (programme design). This will involve the production of a varied and interrelated set of learning experiences which is optimal in the light of the various factors involved. These are discussed in some detail for primary, secondary and vocational and finally university and higher levels.
3. The development and design of the various resource materials and new techniques which can be drawn upon in the design of new courses (component design).
4. Projects which aim at the institutionalization of the analysis and redesign of various parts of science and technology education.

Personnel for science and technology education. This is discussed under the following headings: (a) pre-service training of teachers; (b) pre-service training of special personnel; (c) specialized training courses for high level personnel; (d) maintaining professional competence of personnel.

Operation of the system of science and technology education. The actual operation of a system of science and technology education in accordance with the general plans which have been made and the educational programmes designed under the procedures outlined above will involve heavy investment in institution-building.

Research on science and technology education. Research and design are closely related activities, capable of fruitful interaction, but nevertheless distinct. In developing countries, research should be stressed in those areas where a lack of knowledge is hampering the efforts of designers to develop needed improvements and innovations.

International and regional co-operation. This topic is discussed under the following headings:

1. Exchange of ideas and information: the success of the global programme for the expansion and improvement of science and technology education will require as an indispensable prerequisite a well-established and efficient communication network for the exchange of appropriate ideas and information.
2. Research and development activities: the importance of pooling resources on common problems is stressed and the mechanisms for doing this are suggested.
3. Training activities: emphasis is placed on the need to give adequate language training and orientation facilities to the experts from advanced countries who may work in the developing regions.
4. Regional innovation centres: the need for such centres in both developed and developing countries is discussed.

The special role of Unesco

It bears repeating that the implementation of the World Plan of Action in science and technology education will lean heavily on Unesco. We have already mentioned the technical assistance that has been supplied by UNDP to several countries with guidance from Unesco in the establishment of science teaching improvement centres and in assistance to science and technology faculties in developing countries.

No attempt has been made to look into the details of Unesco's projected plans in science education but no global discussions would be complete without them. The reader is referred to the specific contributions which Unesco made to the World Plan of Action. They fall into four main areas, including areas other than science education: (a) planning of science policy and creation of basic structures; (b) more complete understanding of population problems; (c) more effective use of natural resources; and (d) raising the level of science education including the invention and application of new technologies.

Educational planners should, of course, study the existing and projected programmes of Unesco available at the Offices of the National Commission for Unesco in each of its Member States.

The International Council of Scientific Unions (ICSU) and the improvement of science and technology education

We have already mentioned some of the past activities of the Committee on the Teaching of Science (CTS) of ICSU in areas such as integrated science and educational technology. They were carried

out in collaboration with Unesco and all future activities will undoubtedly be linked with Unesco's programmes.

Two other committees of ICSU—COSTED (Committee on Science and Technology in Developing Countries) and SCOPE (Scientific Committee on Problems of the Environment)—have met with CTS to consider their common concerns in science education. The three committees are planning a programme whose tentative title is 'Natural Resources and the Environment as Integrating Concepts in Science and Technology Education for Developing Countries'. During the ICSU General Assembly held in Istanbul in 1974 officers of SCOPE, COSTED and CTS met to lay the groundwork for future collaboration.

The over-all plan is to conduct seminars in different geographical areas of the developing world in which scientists and educators identify the regional problems of natural resource identification and the possible environmental impact of their utilization. On the basis of this information they hope to develop strategies, modules and teaching methods to be used in pilot science curriculum experiments to assist in the solution of future resources and environmental problems.

The first regional seminar was held, with some assistance from the United Nations Environmental Programme (UNEP) and Unesco, in Ghana in 1975 under the auspices of the Ghanian Academy of Sciences and the University of Ghana, and was devoted to the topics of water and soil and their educational implications.

Other projected CTS activities include:

1. A seminar on the evaluation of integrated science projects. This would be a follow-up of the ICSU/Unesco Maryland Conference on the Education of Teachers for Integrated Science.
2. A seminar on the contribution to school science curricula of disciplines other than biology, chemistry and physics. This would be a small seminar to which the contributors would be members of CTS including representatives from the unions represented on the committees.
3. The interrelationships of science and mathematics is an area of considerable concern. Discussions are being held with ICME (the mathematics education commission of the International Mathematics Union) in order to develop some international activities in this area.
4. A symposium or publication including a bibliography on methods of improving learning strategies in university science is being considered as a collaborative effort with Unesco.

8

Projections for the cost of improvement in science education

Guidelines for tasks and manpower requirements

The need for alternatives to standard cost estimates for projects

The writing of this book began in the early days of the United Nations Second Development Decade (1970–80). The United Nations World Plan of Action (WPA) contains projections for activities in many fields that would stimulate development during this decade along with their estimated costs. Included are the specific needs in science education improvement mentioned in Chapter 7.

In an early draft of this chapter, I quoted extensively from the standard cost estimates given in the WPA since it is, to the best of my knowledge, the only source of such projections in the area of science education improvement.

But while I was writing this book, profound political and economic changes were taking place round the world. It was a time of momentous events. During this interval Western involvement in Indo-China came to an end. A global energy crisis emerged in which power and wealth of enormous magnitude shifted over to the petroleum-exporting countries making some of them potential donors to the Third World in the development arena. Inflation and unemployment afflicted many of the countries of the affluent world. For these and many other reasons, the standard cost estimates for the decade made in WPA for programmes aimed at science education improvement are no longer valid and I have decided not to emphasize them here. The tasks that need to be done in this area, however, have not changed. These are outlined in WPA and I would urge the reader to refer to them. The modes of action that are recommended to bring about reform are still valid and they are well documented there, but

because of the changing world economic scene, the price tags on these activities have changed drastically.

I have decided, therefore, to make this chapter very short and to give only some guidelines on the tasks and manpower requirements for a few typical improvement activities, indicating how they can be run in different ways at different cost levels depending upon where the manpower is obtained and how it is paid for. This might encourage innovators to begin working with local facilities and talent instead of putting off making a start simply because they can not afford to run an activity requiring substantial external support.

What I shall do, therefore, is to describe the work that is to be done and the types of people required for projects without putting emphasis on the corresponding price tag. If the reader is an informed decision maker in either an affluent or a developing country, he can make his own cost estimates if he agrees with my estimates of the man-years and of the type of people required. He will know how many of these people are available within his own country and how many have to be brought in from other countries which, incidentally, might be neighbouring countries whose economic standards are not so different from those of his own. He can estimate how many have to be imported from countries where high-level technology is available. These factors plus other circumstances prevailing at the particular place and time in question will enable him to work out his own budget. I will, in some cases, give realistic estimates of the actual costs of some exemplary low-budget projects.

The need to reorder national priorities

A reordering of national priorities could, I believe, release sizeable funds for science education. Planners and decision makers would probably support science teaching improvement activities if they were convinced that these were relevant to the new priorities for social and economic development such as improvement of food supplies and health services, the preservation and rational utilization of natural resources and a concern for an unpolluted environment. The case for science education improvement will, therefore, have to be put forth vigorously by the scientific and education communities before the planners are convinced that it deserves a high priority. Funds will have to be diverted from areas that yield less benefit. Military spending by the superpowers and now by other countries that aspire to power is, in my mind, a prime example of a gross waste of resources, some of which should be channelled into education.

Illustrative examples of projects and activities

The type of activities in science education improvement which have been funded in the past by private, national and international agencies include: (a) scholarships and fellowships; (b) training courses; (c) workshop seminars; (d) regional pilot projects; (e) conferences and symposia; (f) publications; and (g) science teaching improvement centres. All have played a role in the innovative process world-wide and should continue to be used but I shall not discuss the funding requirements of each one separately as I had originally intended, for the reasons given above. I shall instead analyse a few projects and activities with special reference to those in which local initiatives and economic support played an important role.

The reason for choosing the particular projects that follow is that since the present trend is, unfortunately, for the poor countries to receive less aid from the rich countries, most of the funds for science education improvement projects will have to come from the poor countries themselves. Each of these has access to different kinds of existing resources in the form of personnel already on some payroll or another, workshops and production facilities in technical colleges, facilities for printing such as offset and other processes, and so on. Costs for these and other services vary very much from country to country. The actual costs that will be mentioned are given only as examples that apply locally. Planners in other countries and regions will, nevertheless, be able to substitute realistic estimates that apply to their own situations.

A three-week regional workshop-seminar in Penang

In 1974 a three-week workshop seminar was held in RECSAM, the Regional Centre for Education in Science and Mathematics in Penang. It was directed by Edward Wenham who went as a Unesco consultant. He was assisted by some Unesco science education consultants who were already in Unesco field posts in the Asian region, by the RECSAM staff, and by a physics education expert provided by the German Foundation for International Development (GFID). The funds required came, therefore, from several different sources and some of the manpower was already on payrolls of different organizations. This makes it difficult to tally the total costs precisely, but this is not important here. What is important is that it is possible to run successful projects at a modest cost by utilizing individuals whose salaries come from different sources.

For three weeks, twenty-four Asian physics educators worked under the guidance of the leaders already mentioned. They prepared curriculum materials for physics teachers at the secondary level, mainly in the form of teacher guides. (The actual materials produced by a project depend very much on what is considered to be a high priority local need and what can be realistically accomplished within the limitations of time and resources available. In a one-year Unesco pilot project, for example, other materials including books, kits and films, were produced as well as teacher guides.)

The actual financial contribution of RECSAM would be difficult to estimate, but 'out-of-pocket' expenses were negligible since the services and facilities they provided were accounted by them as part of their normal activities. This was a relatively inexpensive workshop because the participants came mostly from the nearby countries of Asia and because of the comparatively low cost of the RECSAM dormitory facilities.

One important factor has not yet been mentioned. The success of such a project depends to a great extent on the long-range planning that goes into it. This has to be done by individuals who are competent at it and can take the long time necessary to undertake such a task. In the case of this workshop seminar, the planning function was undertaken by staff members of Unesco, GFID and RECSAM, and by the consultants contracted to help in this task. The cost to the permanent organizations of the project officers involved is also a hidden project cost. Without their interest, competence, knowledge and devotion, projects of this sort would never 'get off the ground'.

In summary, then, given sufficient lead time for planning, competent staff officers of permanent institutions, a modest outlay of money from external sources, utilization of local facilities, and lots of unpaid work by local volunteers and participants, it is possible to run a meaningful exercise in science education improvement at a modest cost. There are many examples of the multiplier effect which exercises of this sort have had round the world. They appear in the form of new curricula and new approaches to teaching being practised in different regions due to the impetus supplied by participants at workshop seminars of this sort.

A national seminar in Bolivia

The RECSAM/Unesco/GFID project was an example of a low-cost regional project. To cover a larger region, or if living expenses and some other costs were higher, then a correspondingly higher amount of external funds (plus the contribution of the host institution) would have to be envisaged.

If, on the other hand, about half of the participants are from the host country, and if the meeting takes place in a convenient and

inexpensive location, the cost of such a regional workshop of three weeks' duration might again be brought down considerably.

But if we now consider a national project with no outsiders (except perhaps a resource person or two), the cost of such a workshop comes down considerably.

The questions that have to be answered in estimating costs are, for example: Do the participants have to be paid? Do they have to be fed? Are the facilities free? Will there be any consultants from other countries to bring fresh approaches? If materials are to be produced, how are the printing and other workshop facilities to be accounted for?

Because of the problems associated with such questions it was decided in the 1972 Montevideo seminar mentioned earlier [88] to describe in the report the 'modes of action' required rather than to give budgetary figures. I would urge the interested planner to reread that section. The point is that a national workshop can be run with very little extra money if the directors of the project know how to tap existing local resources.

In early 1969, for example, a Unesco-sponsored four-week seminar was held in Cochabamba (Bolivia). The participants were forty teachers, all from Bolivia. It was directed by two experienced science educators from Argentina hired by Unesco and by a staff member from Unesco. Sets of kits and film materials on 'The Physics of Light' which had been produced in the 1963 pilot project and improved versions of the texts subsequently produced by groups in Argentina were provided for the participants. About $5,000 were spent for the equipment which the participants took home with them to use in their Bolivian schools immediately after the seminar.

Here is a summary of some of the salient points in this example: (a) of the total of $9,000 obtained from external sources, more than half was spent on kits, books, and other materials which the participants took home with them for use in their own schools; (b) the number of Bolivian participants was forty; (c) the duration of the seminar was four weeks; (d) the cost was low, in part because it was a national project with virtually all participants coming from within Bolivia.

Miscellaneous notes on other activities

Exchange of personnel

A very useful way to disseminate new ideas about science education is for individuals—students, teachers, and experienced senior personnel—to travel to other countries to observe different ways of tackling common problems, and to learn through courses, personal contact, and sometimes by actual participation in projects. Ordinary fellowships

may cost between $500 and $700 per month depending on the country the fellow may go to. Senior fellowships may run to roughly between $800 and $1,200 per month, or may sometimes simply consist of the *per diem* at standard United Nations rates—something like a consultantship with *per diem* but without fees. The fellowship also pays for travel and any admission fees that there might be.

Taking into account these last two elements, a junior fellowship for one academic year may add up to about $9,000. In line with my intention to de-emphasize standard costs I repeat that this is just an estimate. The actual figures by the time this book is in press may be quite different.

Let me give an example of a less costly alternative. It mentions specific countries only because I am acquainted with individuals there who play the roles I am about to suggest. Suppose a person A from a permanent working group in Mexico goes to work for, say, three months in a permanent working group in Brazil. Suppose also that a member B from the Brazilian group goes to work for three months in a permanent working group in Peru. (The duration need not be the same for A and B.) Suppose that both A and B continue to receive their salaries as usual from their permanent institutions so that there is no change in how they handle their own living expenses including those of their families. In both cases, let us assume that the host institution pays for the living expenses of the guest (in other words what is normally called the *per diem*). Suppose, finally, that Unesco or some other external agency interested in promoting science teaching improvement internationally pays for the travel expenses of A and B. The result is that two short fellowships have been created and the cost has been shared (probably painlessly since the actual extra amounts are very modest) by the permanent institutions from which A and B came, by the host institutions and by the external agency.

I have purposely described the procedure in detail without giving actual costs because these can easily be figured out for the particular individuals and institutions involved. The important thing is the idea of how exchange of personnel can be effected without resorting to budget estimates based on standard costs. Details of this and other ideas are given in the report on the Montevideo seminar [88].

Publications

I shall use the Unesco 'New Trends' series as examples of how different volumes even in the same series cost different amounts simply because the procedures used to produce them vary over a wide range.

Some of the early volumes consisted mainly of reprints which were not paid for. It was simply a matter of getting the permission to reproduce them, making a rational selection and doing some editorial work which explained the rationale of their choice. This is

the procedure, incidentally, that was recommended to Unesco by a group of experts who had had ample experience in the publication of different scientific and science education journals round the world.

Later, when sales indicated that there was interest in the 'New Trends' idea, that is, that people were buying them in numbers over and above the free distribution which Unesco normally makes of such publications, slightly higher amounts were budgeted for the preparation of subsequent volumes. This made it possible to commission authors to write papers specially for the 'New Trends' volumes and not to rely solely on reprinted materials.

A very effective alternative technique is to bring all the authors of the 'New Trends' publication together after they have had a chance to read the work of all the other authors. Such meetings have often been paid for by Unesco and held at Unesco Headquarters in Paris. The authors and a paid editor get together to criticize all the papers. On the basis of these discussions the editor puts together a final version representing the consensus of the group. A good example of a volume resulting from the technique is Volume II of *New Trends in Integrated Science* [53].

Still another technique is to commission state-of-the-art papers on a given subject from experts in their respective fields and to use these as the basis of a meeting at which not only the authors but other experts in the general area of interest are brought together for a rather broad-ranging discussion of related issues and not simply as an editorial board. Rapporteurs, permanent Unesco staff members and others are present to take notes which will assist in the final editing procedure. A good example of a publication produced by this technique is the *New Trends in the Utilization of Educational Technology for Science Education* [63]. The cost of doing things this way includes a fee paid to each of the authors, the cost of bringing them together in Paris (shared in this case between ICSU and Unesco) and the cost of editing and printing of the book. The whole activity, which includes what amounts to running a small symposium with about twenty people, comes to roughly $24,000 plus permanent staff time. It can be done for less if the printing is given out to a commercial publisher —a procedure often used for Unesco publications.

If, instead, it is decided to run a full-fledged conference on the subject with 200 to 300 participants and to use their contributed papers as the basis for another kind of publication, the cost naturally goes up still further. I will not put down even a rough estimate because this type of activity can take place in so many different ways that any estimate for the publication aspect would be misleading. I need only say that people who have been responsible for running such conferences and putting out their proceedings as a publication can tell you that this is a costly and time-consuming procedure.

In summary, using the Unesco 'New Trends' series as an illustration, various volumes have been put out with the cost of

preparation of the final version ranging from roughly $10,000 to $20,000 excluding cases also involving a large conference.

I believe that there is need for other types of publications to reach the interested target population more effectively and more rapidly than the present publications of Unesco and other organizations. Short, properly edited newsletters sent periodically by airmail to carefully selected individuals and institutions would improve the dissemination of information and need not be very costly.

Many of the publications put out by the Regional Offices of Science and Education of Unesco are of a very high standard of editorial and printing quality and have been produced rapidly and at low cost.

Conferences

Conferences have been a classic mode of action for international organizations. They represent the activity which has been most severely criticized and, at the same time, probably most widely used. For every participant who says, 'It was a waste of time', there is probably another who says, 'I am glad I attended'. (In fact, the same participant may, at different times, say both!)

The reason for the criticisms are well known. Conferences are costly and difficult to organize. Their preparation is extremely time consuming. Successful ones that I know of have had a lead time of three years or more. They are difficult to run. There are problems of housing, simultaneous interpretation, scheduling of conference halls and rooms for working parties and seminars, etc. Even more difficult is the intellectual preparation—the specification of objectives, the choice of topics and speakers and, almost impossible to achieve, the evaluation.

In spite of all this, international conferences continue to be planned and held for several reasons. One is that they have a high visibility. They give publicity and occasionally even renown to the organizations responsible for the planning—hence the continued pressure to spend large amounts of money on running them.

On the positive side, they do provide a public forum for the exchange of ideas and the possibility of their dissemination through publications. They also provide private opportunities, usually in the corridors and at the dining tables rather than in the form of sessions, for the informal discussions which may, after all, be most valuable. They can have a morale boosting effect on the participants and, through the dissemination of their results, can raise the level of consciousness of a large number of people concerning a particular topic, especially if a 'workshop' atmosphere is developed by getting as many attenders as possible to participate in the discussions.

Now, an 'order-of-magnitude' estimate of costs. In 1975 the cost of running a conference in Europe with world-wide participation of

about 350 participants was roughly $100,000. This covered all visible and invisible costs and the travel and living expenses of about 50 participants, mostly from developing countries, but not the travel and living expenses of the remaining 300 participants. They, of course, had to find their own funds. To give much more accurate figures would be misleading since the actual cost of any conference will vary greatly with time and place.

My personal advice would be not to hold large conferences if you can devise and undertake more imaginative and direct action such as the actual production of teaching materials in the field by the people who will ultimately use them.

A suggested regional activity

Consider a region such as Africa or Latin America where some national science education improvement projects already exist. External funds from Unesco and other organizations could be used to (a) support the efforts of existing national groups and stimulate the formation of new ones; (b) provide funds for the exchange of persons within the region; (c) organize a number of regional workshops —perhaps about six in a year—in different countries, all of this as part of a coherent programme; (d) provide the services of consultants for the workshops and for helping the national groups (including funds for travel of the consultants and for the equipment to be left behind where required).

A rough estimate, not calculated on the old basis of standard costs but on the more flexible approaches suggested in earlier sections would be about $300,000 per year or possibly $500,000 for a period of two years. This is, of course, only for one region—say, Africa or Latin America but not both.

Such a project would be a kind of extension of Unesco's original pilot project idea. It would be an activity quite apart from the establishment of permanent institutions devoted to science education improvement which are, of course, in the main the responsibility of the individual countries themselves.

Establishment of permanent institutions

The establishment of permanent institutions just mentioned was discussed in detail in Chapter 5. It remains to say something, with due caution, about cost. In the 1960s it was customary to conceive of the establishment of a teacher training college or a permanent centre for the improvement of science teaching as a national project for which the United Nations Development Programme would supply roughly $1 million over a period of about five years with matching funds of the same order or higher from the recipient country.

In some recent cases, the UNDP contribution has been roughly

$300,000 per year over a period of six years, in two phases with a mid-term review at the end of the first three years to determine whether or not to carry on with the second phase.

But there is no set pattern and one of the recently established national science education improvement centres received a total of only about $500,000 from UNDP over a period of five years with a much larger contribution from the country itself.

These figures may give a rough idea of the external inputs to a permanent institution. It would be much more useful, however, for the planners to study the details of man-years of expert services required, of the types and number of fellowships needed, and of all the many other factors involved. Any government considering seriously the creation of a permanent institution would do well to study documents available at Unesco showing how the breakdown of functions and costs were effected for existing centres, keeping in mind that they too must be used only as guidelines. The details need to be worked out over a period of several years before funding is made available.

I have come to the conclusion, forced upon me by a consideration of recent developments, that I cannot give realistic estimates for the cost of a specific institution. Even if I could, it would not be very helpful to the planners of the institution because what they need to figure out is just what they expect will happen at their centre and how many man-years of what kinds of experts are required. They need to figure out how long it will take to train their own people (training on the job)—who will eventually have to take over when the outside consultants leave—and how they will obtain the necessary interpersonal, interdisciplinary, and interinstitutional co-operation. These are the crucial issues. Money is necessary but not sufficient.

Annotated bibliography

1. Lewis, L. J. (ed.). *The learning process and the teaching of science and mathematics in developing countries.* New York, N.Y., United Nations Economic and Social Council Advisory Committee on the Application of Science and Technology to Development. (Doc. STD/8/1B, 19 September 1967.)

   Describes in outline the relations between the learning process, the traditional views held in non-technical society of natural phenomena and cosmology and the development of the teaching of science and mathematics. Contributions by J. Bruner, D. Lee, C. Rogers and R. H. Stone.

2. Baez, Albert V. *Improving the teaching of science with particular reference to developing countries.* New York, N.Y., United Nations Economic and Social Council Advisory Committee on the Application of Science and Technology to Development. (Doc. STD/8/1A and Corr. 1, 10 October 1967.)

   Considers the impact of science and technology on economic and social development, the need for improvement in science education and criteria for a programme of action, a review of activities in course improvement and curriculum reform in science and ends with specific recommendations for a concerted action on science teaching improvement in developing countries.

3. United Nations Economic and Social Council. *First report on science education prepared by the Advisory Committee on the Application of Science and Technology to Development.* New York, N.Y., United Nations, 1968. (Doc. E/4448.)

   Contains recommendations of the Advisory Committee under the following headings: (a) the work of the Division of Science Teaching at Unesco; (b) a working party for the consideration of science education; (c) international centre for science teaching development and demonstration; (d) publications; and (e) implementation of the recommendations of the Advisory Committee.

4. Page, J. K.; Reswick, J. B. What is designing? In: J. Christopher Jones, *Design methods*, p. 3-12. London, John Wiley & Sons, 1970. xvi + 407 p.

   Reviews ancient and modern design methods. New methods are

described and classified. Contains an outline with examples of thirty-five new methods.

5. BAEZ, Albert V.; ALLES, Jinapala. Integrated science teaching as part of general education. In: Unesco, *New trends in integrated science teaching*, vol. II, p. 167-75. Edited by P. E. Richmond. Paris, 1973. 239 p., illus., bibliog.

   Broad guidelines for future integrated science courses for general education are proposed centred around the concepts of inquiry, concern, and ability to solve real problems. The last is associated with the spirit of change through design.

6. FOECKE, Harold A. Engineering in the humanistic tradition. *Impact of science on society*, vol. XX, no. 2, 1970, p. 125-35.

   Argues that the engineer's education should, because of his social responsibility, include much more training in the human and social sciences than is provided now.

7. PEARSON, Lester B. *Partners in development*. New York, N.Y., Praeger, 1969. xvi + 399 p. (Two decades of development, 23.)

   This is the report of the Commission on International Development of which L. B. Pearson was chairman. It was created by the World Bank to study the consequences of twenty years of development assistance, to assess the results, clarify the errors and propose policies which will work better in the future.

8. *Estimates by Barclays Bank International Ltd*, based on the *World Bank atlas 1972*, published by International Bank for Reconstruction and Development, 1818 H Street N.W., Washington, DC 20433.

9. BROWN, Harrison. The role of science and technology in development. In: R. Esquinazo-Mayo, K. M. Shahani and S. B. Treves (eds.), *Proceedings of symposium on the scientific and technological gap in Latin America*, p. 4-31. Lincoln, Nebr., University of Nebraska, 1973.

10. MCNAMARA, Robert S. Address to the University of Notre Dame, Indiana. 1 May 1969.

    Discusses the tangled problems of excessive population growth. Available from the International Bank for Reconstruction and Development, 1818 H Street N.W., Washington, DC 20433.

11. SNOW, C. P. *The state of siege*. New York, N.Y., Charles Scriber's Sons, 1969.

    Humanity faces a food–population collision. To meet this crisis Snow urges us to break out of our state of siege in order to collaborate in the responsibility of our time.

12. The Menton statement. *Dai-Dong newsletter* (Nyack), September 1972.

    This statement on environmental deterioration, depletion of natural resources, population, hunger and war was signed by over 3,000 scientists from twenty-nine countries in 1970. The statement led to an Independent Conference on the Environment near Stockholm in 1972.

13. ROSE, Steven. Science and its social consequences. *The Times higher education supplement* (London), 11 November 1971, p. 13, 14.

    Asks whether science can be neutral. Attempts to clarify issues which are critical to an understanding of the role of science in modern society and indicates a direction for science if it and mankind are to survive.

14. HARBISON, Frederick; MYERS, Charles A. *Education manpower and economic growth*, p. 38. New York, McGraw-Hill Book Co., 1964.

15. *A study of the capacity of the United Nations development system*, vols. I and II combined, p. 38. Geneva, United Nations, 1969. xi + 487 p.
R. G. A. Jackson was commissioned to assess the capacity of the United Nations system to make effective use of the resources of the United Nations Development Programme and its capacity to handle a programme approximately double that of the existing operation within the next five years. This is his report—often referred to simply as 'the Jackson report'. On page 55 he quotes from a speech made by K. B. Asante.
16. CLARKE, Robin. *The great experiment. Science and technology in the second United Nations development decade.* New York, United Nations, 1971. 54 p.
Describes briefly the formation of the United Nations Advisory Committee on the Application of Science and Technology to Development (ACAST) which arose out of the 1963 United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas (UNCSAT) and the priority areas which they chose. It outlines the proposals of a World Plan of Action for action during the decade 1970–80.
17. COOMBS, Philip H. *The world educational crisis. A systems analysis.* New York, N.Y. Oxford University Press, 1968. vii + 241 p.
Aims to assemble in one place the root facts about an unfolding world crisis in education, makes explicit the tendencies inherent in these facts and suggests the elements of a strategy for dealing with them. The second aim is to present a method for looking at an educational system as a system whose interacting parts produce their own 'indicators' as to whether the interaction is going well or badly. Contains numerous useful tables and appendixes.
18. NATIONAL SCIENCE FOUNDATION. *Interactions of science and technology in the innovative process: some case studies; final report.* Columbus, Battelle Columbus Laboratories, 1973. Twelve chapters.
Retrospective case studies documenting historically the significant events in several technological innovations of high social impact to illustrate the diverse ways by which research and development activities support each other in the innovative process. The cases covered are: the heart pacemaker, hybrid grains and the green revolution, electrophotography, input-output economic analysis, organo-phosphorous insecticides, oral contraceptives, magnetic ferrites, and the video tape recorder.
19. PRICE, William J.; BASS, Lawrence W. Scientific research and the innovative process. *Science* (Washington), vol. 164, 16 May 1969, p. 802-6.
The dialogue between science and technology plays an important but usually nonlinear role in innovation.
20. DE SIMONE, Daniel V. (ed.). *Education for innovation.* London, Pergamon Press, 1968. ix + 180 p.
Organizes the informal talks of a conference held at Woods Hole concerning: (a) the influence of the educational environment on creativity; (b) the stimulation of creative engineering education; (c) the process of invention and how to teach it; (d) the process of innovation and how to teach it; and (e) what might be done to support the development of creative engineering education.

21. GATEWOOD, Claude W.; OBOURN, Ellsworth S. Improving science education in the United States. *Journal of research in science teaching*, vol. 1, 1963, p. 355-99.

A fairly complete statement of the situation in the United States in 1963. Discusses (a) historical and educational background; (b) changing science curricula; (c) implementation of reform in the schools; and (d) problems and issues, trends and outlook.

22. NATIONAL SCIENCE FOUNDATION. *Course and curriculum improvement projects.* Washington, D.C., 1970. vii + 43 p.

Summary information on curriculum studies, textbooks, laboratory guides, resource materials for teachers, supplementary materials for students, equipment development and films in mathematics, science and the social sciences.

23. GOODLAD, John I.; VON STOEPHASIUS, Renata; KLEIN, Frances M. *The changing school curriculum.* New York, N.Y., The Fund for the Advancement of Science Education, 1966. 122 p.

Discusses many projects illustrative of the reform movement in education in the United States starting in the 1950s and including science and mathematics projects.

24. LOCKARD, J. David (ed.). *Eighth report of the international clearinghouse on science and mathematics curricular developments, 1972.* College Park, Md, Commission on Science Education of the American Association for the Advancement of Science and the Science Teaching Center, University of Maryland, 1972. xxxvi + 858 p.

Describes (a) projects listed alphabetically by geographical area (African, Asian and Australian areas, Canada, Caribbean area, Europe, Middle East area, South American area, Unesco and the United States); (b) directors of projects outside the United States; (c) directors of projects inside the United States; (d) projects outside the United States; (e) projects inside the United States; (f) completed or inactive projects. A ninth report has since been published but only references to the eighth report will be made in this book. The ninth report has the title *Science and Mathematics Curricular Developments internationally, 1956-74.* A one-page summary is devoted to each project.

25. BAEZ, Albert V. Aims, contents and methodology in science teaching. In: Gillon, Philip and Hadassah (eds.), *Science and education in developing states.* New York, N.Y., Praeger Publishers, 1971. xiv + 288 p.

One of thirty-two papers included in the proceedings of the fifth Rehovot Conference sponsored by the Hebrew University of Jerusalem and the Weizmann Institute of Science which brought together 115 participants from 54 countries. Among the delegates were twenty cabinet ministers and two deputy cabinet ministers, forty-five administrators in the field of education and forty-eight scientists.

26. OECD. *Teaching physics today-some important topics.* Paris, Directorate for Scientific Affairs, Organization for Economic Co-operation and Development, 1965. 269 p.

This is the tenth volume in the series 'New Thinking in School Science' produced by OECD. Other volumes dealt with chemistry, biology and mathematics.

27. BROWN, Sanborn C.; KEDVES, F. J.; WENHAM, E. J. (eds.). *Teaching physics.*

An insoluble task? Cambridge, Mass., MIT Press, 1971. xv + 261 p.

Proceedings of the International Congress on the Education of Teachers of Physics in Secondary Schools, Eger (Hungary), held in September 1970 and sponsored by the International Commission on Physics Education of the International Union of Pure and Applied Physics (IUPAP) with support from the Hungarian Government and Unesco.

28. SIKJÆR, Søren (ed.). *Seminar on the teaching of physics in schools.* Copenhagen, Gyldendal, 1971. 214 p.

A seminar sponsored by the Groupe International de Recherche sur l'Enseignement de la Physique (GIREP) at the Royal Danish School of Educational Studies in Copenhagen in 1969. It dealt mainly with how the topic of energy is treated in junior high school and how quantum physics and the special theory of relativity are handled in senior high school.

29. DIVISION OF INTERNATIONAL EDUCATION. INTERNATIONAL EDUCATIONAL RELATIONS BRANCH. UNITED STATES DEPARTMENT OF HEALTH, EDUCATION AND WELFARE. OFFICE OF EDUCATION. *Education in the USSR.* Washington, D.C., United States Government Printing Office, 1957. ix + 226 p. (Bulletin 1957, no. 14.)

Discusses planning, administration, organization and curriculum from pre-school to higher education. It includes sections on auxiliary schools, extracurricular work activities, vocational training and teacher training. Contains numerous tables and illustrations.

30. YELYUTIN, V. *Higher education in the USSR.* Moscow, Novosti Press Agency Publishing House, [1967], 80 p.

Describes the development of higher education in the U.S.S.R., its structure, what specialists are graduated by colleges for the different branches of the economy, science and culture, what is being done to bring liberal arts and technical education more in line with the needs of the day and how the system of training is organized. It has a chapter on scientific work in the colleges.

31. LEWIS, J. L. Physics teaching in the USSR. *The new scientist* (London), vol. 12, p. 112-14.

Concludes that the U.S.S.R. accepts that it will never have enough good teachers and consequently provides the material to enable the indifferent teacher to teach well. His verdict is that Britain is in danger of lagging far behind the U.S.S.R. in particular if it fails to grasp the importance of good demonstration equipment, films and other visual aids.

32. WIENERT, Helgard. The Vuzy: Soviet high education. *Science and technology*, no. 88, April 1969, p. 22-34.

Education is viewed by Soviet planners as a powerful weapon in their avowed race to overtake the West in science and technology. In effect, education is far more seriously regarded in Russia than it has been in the United States. Moreover, Soviet teachers and professors are regarded as soldiers 'standing in the advanced line of fire'. The report is slanted toward education in science and technology rather than toward fine arts or the social sciences.

33. LEWIS, J. L. Education in the USSR with particular reference to physics. *Bulletin of the Institute of Physics and the Physical Society*, July 1961, p. 189-96.

34. Unesco. *Pilot project on the teaching of physics.* Paris, 1967. 80 p. + diagrams of equipment and photographs from films. (Doc. SC/WS/160.)
Available in English, French and Spanish, free of charge from Unesco within limitations of existing stock of copies.

35. Ferreyra, Rafael Eduardo. *The Unesco pilot project on the teaching of physics. A history and critical appraisal after ten years.* Cambridge, Mass., Harvard University, 1974. 227 p. (Doctoral dissertation.)
Ferreyra was a participant in the project, utilized the project materials in teacher training in Argentina and later assisted in the spread of their use through seminars in different Latin American countries in some cases with support from Unesco. He received the degree of doctor of education from Harvard University in 1974.

36. Cohen, Bernard I. Galileo, Newton and the divine order of the solar system. In: Ernan McMullin (ed.), *Galileo, man of science*, p. 207-31. New York, N.Y., Basic Books Inc., 1967.
Compares arguments put forth by Plato, Galileo and Newton concerning the creation of the solar system and the physical law of gravitation which governs the motion of the planets.

37. Margenau, Henry. The new view of man in his physical environment. *The centennial review of arts and sciences*, vol. 1, no. 1, winter 1957.
Asserts that the results of physical science are of extraordinary importance to an understanding of the nature of man and that this peculiar relevance, hitherto largely ignored, is greatly in need of exposition and emphasis.

38. Ward, Barbara; Dubos, René. *Only one earth. The care and maintenance of a small planet.* Harmondsworth, Middlesex, Penguin Books, 1972. 304 p.
This unofficial report, read and revised by more than 150 expert consultants from many countries and fields was designed to set the key for the United Nations Conference on the Human Environment held in Stockholm in June 1972. Describes the earth's swelling population, its resources, the knowledge, energy and industry that form man's potential as well as the squalid details of technology's impact on soil, sea and air. Discusses the different impact of these matters on industrialized and developing countries.

39. Commoner, Barry. *The closing circle. Confronting the environmental crisis.* London, Jonathan Cape, 1971. 336 p.
Attempts to describe what the environmental crisis really means and how survival depends on understanding that the ecosphere sustains people and everything they do and that anything that fails to fit into the ecosphere is a threat to its finely balanced cycles.

40. Hammond, Allen L.; Metz, William D.; Thomas H. Maugh II (eds.). *Energy and the future.* Washington, D.C., American Association for the Advancement of Science, 1973. xii + 184 p.
The general thesis of the book is that the United States cannot afford to be without more energy options than it has at present. The main topics are (a) energy from fossil fuels; (b) nuclear energy; (c) alternative energy sources; (d) energy transmission; (e) energy conservation; and (f) energy policy.

41. Committee on Resources and Man. National Academy of Sciences —National Research Council. *Resources and man.* San Francisco, Calif., W. H. Freeman & Company, 1969. ix + 259 p.

Official non-technical report of a committee established to examine the question of resources and man. Emphasis is placed on the issues of resource adequacy central to a realistic assessment of the problem rather than on detailed estimates or projections.

42. EHRLICH, Paul R.; EHRLICH, Anne H. *Population, resources, environment. Issues in human ecology.* San Francisco, Calif., W. H. Freeman & Company, 1970. 383 p.

    The chapter titles are: 'The Crisis'; 'Numbers of People'; 'Population Structure and Projection'; 'The Limits of Earth'; 'Food Production'; 'Environmental Threats to Man'; 'Ecosystems in Jeopardy'; 'Optimum Population and Human Biology'; 'Birth Control'; 'Family Planning and Population Control'; 'Social, Political and Economic Change'; 'The International Scene'; 'Conclusion'.

43. DEBELL, Garrett (ed.). *The environmental handbook.* New York, N.Y., Ballantine, 1970. xi + 367 p.

    A set of readings from many sources produced for the first national environmental teach-in by the Friends of the Earth organization, on the meaning of ecology and suggestions for individual and political action.

44. HARDIN, Garrett (ed.). *Population, evolution and birth control. A collage of controversial ideas.* 2nd ed. San Francisco, Calif., W. H. Freeman & Company, 1964. xvi + 386 p.

    A collection of 123 essays and articles from authors as varied as Malthus, Han Fei-Tzu, Benjamin Franklin, Kenneth Boulding and Robert Frost knit together by Hardin and including some of his own writings.

45. PLATT, John Rader. *The step to man.* New York, N.Y., John Wiley & Sons, 1966. 216 p.

    Concerned with the evolving nature of man, social and intellectual; what he is and what he may become. Some chapters have previously appeared in journals or books.

46. FAURE, Edgar; HERRERA, Felipe; KADDOURA, Abdul-Razzak; LOPES, Henri; PETROVSKY, Arthur V.; RAHNEMA, Majid; WARD, Frederick Champion. *Learning to be.* Paris, Unesco, 1972. xxxix + 313 p.

    Report of the International Commission on the Development of Education on the general theme of the world of education today and tomorrow in three parts: (a) Findings; (b) Future; (c) Towards a learning society. Chapter titles are: 'The Question of Education'; 'Progress and Dead Ends'; 'Education and Society'; 'Challenges'; 'Discoveries'; 'Goals, Role and Function of Educational Strategies'; 'Elements for Contemporary Strategies'; 'Roads to Solidarity'.

47. WEST, Felicia E. (ed.). *Science for society. A bibliography.* 5th ed. Washington, D.C., Commission on Science Education, American Association for the Advancement of Science, 1974. v + 105 p.

    A bibliography concerned with all aspects of the interrelations of man, society, environment, science and technology. It is important to note that unlike previous editions where approximately one-fourth of the entries were carried over from the preceding year, all the entries in the fifth edition are new. The interested reader may, therefore, wish to consult previous editions for additional titles. Entries are annotated and interest groups are indicated. There is a topic-author index.

48. Mood, Alex M. Diversification of operations research. *Operations research*, vol. 13, no. 2, March-April 1965, p. 169-78.
49. Durstine, Richard M.; Davis, Russell G. Educational planning in developing countries. *Operations research*, vol. 17, no. 5, September-October 1969, p. 911-15.
50. Weyer, Edward M. (ed.). A systems approach to technical education. *Annals of the New York Academy of Sciences* (New York), vol. 136, 12 October 1967, art. 24, p. 755-78.
    Bertram Spector: Why a systems analysis of technical education; Theodore K. Steele: Operational considerations; Leo R. Eilbert: The role of measurement in project ULTRA.
51. Carter, Launor F. *The systems approach to education—the mystique and the reality*. Systems Development Corporation, Santa Monica, Calif., 27 January 1969. (SP-3291.)
    Available from Systems Development Corporation, 2500 Colorado Ave., Santa Monica, CA 90406 (United States).
52. Bixby, Louis W. Science and values. A systems approach to learning science. *The independent school bulletin*, vol. 28, no. 3, February 1969, p. 60.
53. Unesco. *New trends in integrated science teaching*. Paris, Vol. I: *1969–1970*, prepared by P. E. Richmond, 1971, 381 p.; vol. II, edited by P. E. Richmond, 1973, 239 p.; vol. III: *Education of teachers*, edited by P. E. Richmond, 1974, 227 p.
    Volume I contains reprints of many articles collected internationally to define and illustrate integrated science. It also contains a few commissioned articles. Volume II contains nine commissioned articles and some examples of projects. Volume III is based on the proceedings of the ICSU Conference on 'The Education of Teachers for Integrated Science —Teaching Science for Today's Society', held at the University of Maryland, United States, from 3 to 13 April 1973.
54. *International Conference on Education of Teachers for Integrated Science. Report.*
    Available from D. G. Chisman, The British Council, 10 Spring Gardens, London W.C.1 (United Kingdom). Price $1.25 or 50p postage free. Copies of the report of the Congress on Integration of Science Teaching held in Droujba may still also be available from this source.
55. Educational Development Center/Centre for Curriculum Renewal and Educational Development Overseas. *Methodology for a new approach in the primary school in Africa*. From a report of the Conference of African Educators, EDC and CREDO, Mombasa (Kenya), September 1967. In: Unesco, *New trends in integrated science teaching*, vol. I, contribution no. 6.
56. Goodlad, John I. Integrated science, teacher education and the improvement of schooling. In: Unesco, *New trends in integrated science*, vol. III, p. 111-20. Paris, 1974.
57. Rutherford, James; Gardner, Marjorie. Integrated science teaching. In: Unesco, *New trends in integrated science teaching*, vol. I, p. 47-55. Paris, 1971.
58. Hall, William C. Case study in curriculum decision making: The Schools Council integrated science project 'Case study in curriculum decision

making'. *Australian science teachers' journal*, vol. 17, no. 3, October 1971.

59. MUÑOZ, Hector M. Science education in other countries—Chile. *Science education news* (Washington, D.C.), September 1970, p. 2.

    This issue also contains articles about Brazil, Germany, Japan, Nigeria, the Philippines and Slovenia (Yugoslavia).

60. UNITED NATIONS CHILDREN'S FUND. *Eve science rev. 2* (second revision of Unicef guide list *Eve*) New York, 1973. iv + 107 p. (United Nations publication OSU-6000.1.)

    Contains a discussion of new trends in science teaching, teacher training, curriculum development and the types of equipment which Unicef supplies for primary and secondary science teacher training in science and development of science curricula. Done in collaboration with Unesco.

61. UNITED NATIONS CHILDREN'S FUND. *Illustrations of science teaching apparatus and equipment available from Unicef* (corresponding to the items listed in *Eve science rev.*, the 1972 revision of the science teaching sections of Unicef guide list *Eve*). New York, 1973. xii + 27 p. English/French/Spanish. (United Nations publication OSU-6000, supplement 1.)

    A very useful visual supplement to the *Eve* list. Makes ordering of equipment much easier than reading a list of items.

62. JOEL, Nahum. *Improving the initial and in-service education of science teachers by involving them in the process of designing new science courses.*

    A paper presented at the meeting on 'Science and Man in the Americas' jointly sponsored by the American Association for the Advancement of Science (AAAS) and the Consejo Nacional de Ciencia y Tecnologia (CONACYT) of Mexico, held in Mexico City, 25-30 June 1973. A limited supply of this paper may be available from the author at Unesco, 7 Place de Fontenoy, 75700 Paris (France).

63. UNESCO. *New trends in the utilization of educational technology for science education.* Paris, 1974. 247 p.

    This volume contains the state-of-the-art papers prepared for a meeting convened by Unesco and the Committee on the Teaching of Science (CTS) of the International Council of Scientific Unions (ICSU) from 13 to 16 September 1972. It explores current trends to improve the teaching and learning of science at all levels. The topics covered, all dealing with science education, were: computer-based science education, programmed learning, television, radio, learning media, integrated multimedia systems which achieve a wide territorial coverage as well as those that exclude television and radio broadcasts, the professional training of science teachers and applications to developing countries.

64. LEITH, George O. M. Programmed learning in science education. In: Unesco, *New trends in the utilization of educational technology for science education*, p. 34-51. Paris, 1974. 247 p.

65. BERMAN, Arthur I. Learning media: theory, selection and utilization in science education. In: Unesco, *New trends in the utilization of educational technology for science education*, p. 102-42. Paris, 1974. 247 p.

66. BITZER, Donald L.; SHERWOOD, Bruce Arne; TENCZAR, Paul. Computer-based science education. In: Unesco, *New trends in the utilization of educational technology for science education*, p. 18-32. Paris, 1974. 247 p.

67. VALÉRIEN, J. The use of television in science teaching. In: Unesco, *New*

trends in the utilization of educational technology for science education, p. 54-68. Paris, 1974. 247 p.

68. BALL, John C. H. The use of radio in science education. In: Unesco, *New trends in the utilization of educational technology for science education*, p. 70-100. Paris, 1974. 247 p.
69. KAYE, A. R.; PENTZ, M. J. Integrated multi-media systems for science education which achieve a wide territorial coverage. In: Unesco, *New trends in the utilization of educational technology for science education*, p. 144-84. Paris, 1974. 247 p.
70. POSTLETHWAIT, S. N.; MERCER, Frank V. Integrated multi-media systems for science education (excluding television and radio broadcasts). In: Unesco, *New trends in the utilization of educational technology for science education*, p. 186-220. Paris, 1974. 247 p.
71. PERLBERG, A. Educational technology in the professional training of science teachers. In: Unesco, *New trends in the utilization of educational technology for science education*, p. 222-39. Paris, 1974. 247 p.
72. LOMAN, D.; KAYE, A. R. *Educational technology: its use for the improvement of science and mathematics education. (A review of the literature)*. Paris, Unesco, [unpublished].

    Includes a four-page introduction on terminology and definitions, an annotated bibliography with over 400 entries and 24 pages of 'topic notes' which, under about 70 headings, provide cross-references to a selection of the most significant annotated items.
73. MERWIN, Jack C. Historical review of changing concepts of evaluation. In: *Sixty-eighth yearbook of the National Society for Education*, chapter II, p. 6-25. Chicago, Ill., University of Chicago Press, 1969.
74. TYLER, Ralph W. The curriculum—then and now. In: *Proceedings. 1956 invitational conference on testing problems*, p. 81. Princeton, N.J., Educational Testing Service, 1957.
75. PROTOPAPAS, Paul N. The Keller Plan implementation of the personalized system of instruction in a freshman biology course. *The science teacher* (Washington, D.C.), vol. 41, no. 5, May 1974, p. 44-6.
76. GREEN Jr, Ben A. Physics teaching by the Keller Plan at MIT. *American journal of physics* (New York), vol. 39, July 1971, p. 764-75.

    This paper reports experience with the plan in introductory physics. The results are strongly favourable. Students report that they learn materials more thoroughly and more efficiently. Lectures are used sparingly and mainly for motivation.
77. KOEN, B. V.; KELLER, F. S. Experience with a proctorial system of instruction. *Engineering education*, March 1971, p. 504-5.

    This article includes the experiences and valuations of classroom engineering teachers who have designed and operated systems intended to individualize or personalize instruction.
78. KULIK, James A.; KULIK, Chen-Lin; CARMICHAEL, Kevin. The Keller Plan in science teaching. *Science* (Washington, D.C.), vol. 183, 1 February 1974, p. 379.
79. POSTLETHWAIT, S. N.; NOVAK, J.; MURRAY Jr, H. T. *The audio-tutorial approach to learning*. 2nd ed. Minneapolis, Minn., Burgess Publishing Company, 1964. v + 149 p.
80. ROGERS, Eric M. *Improving physics education through the construction and discussion of various types of tests*. Paris, Unesco, 1971. 119 p.

Report of a Latin American workshop seminar held by Unesco in Montevideo in January 1971. Also available in Spanish (93 p.) from the Unesco Science Office for Latin America, Casilla de Correo 859, Montevideo (Uruguay), under the title: *Enseñanza de la Física, su Mejoriamento a través de la Construcción y Discusión de Varios Tipos de Pruebas.*

81. UNESCO. *New trends in physics teaching*. Vol. I. Paris, 1968. 271 p.
82. FERREYRA, Rafael E. Laboratory experiments and other activities in a multi-media approach to the teaching of physics. In: Unesco, *New trends in physics teaching*, vol. II, p. 197-219. Paris, 1972. 517 p.
83. FERREYRA, Rafael E. The Unesco physics pilot project: follow-up and adaptation in Argentina and Bolivia. In: John L. Lewis, *Teaching school physics*, Penguin Books and Unesco, 1972. 416 p.
    Ferreyra has also written a doctoral dissertation for Harvard University entitled: *The Unesco Pilot Project for the Teaching of Physics, São Paulo, Brazil, 1964. A History and Critical Appraisal after Ten Years*, Cambridge, Mass., Harvard University, 1974, 227 p.
84. UNESCO. *Final report and evaluation of the Unesco pilot project for chemistry teaching in Asia*. Paris, 1972. 85 p. (Doc. SC/WS/505.)
    Available free of charge from Unesco while stocks exist.
85. UNESCO. *Final report of the pilot project on new approaches and techniques in biology teaching in Africa*. Paris, 1972. 19 p. (Doc. SC/MD/32.)
    Available in English and French free of charge from Unesco while stocks exist.
86. BREDEMEIER, Kenneth. Teenagers produce science kits for Fairfax elementary pupils. *The Washington post* (Washington, D.C.), 7 January 1971, p. B3.
87. UNESCO. *Regional seminar on school science equipment* (Final report of the seminar convened by Unesco in co-operation with the Government of India and Unicef). Bangkok, Unesco Regional Office for Education in Asia, 1973. 65 p.
88. UNESCO. *La enseñanza de las ciencias en América latina* [The teaching of sciences in Latin America]. Montevideo, Oficina de Ciencias de la Unesco para América Latina, 1973. 113 p.
    Latin American seminar on the improvement of the teaching of science held in Montevideo, 5-15 December 1972. An English version of Chapter I of this report is available from Unesco, Paris. It contains a complete table of contents.
89. UNESCO. *Teaching school physics. A Unesco source book*. Edited by John L. Lewis. Harmondsworth, Middlesex. Penguin Books and Paris, Unesco, 1972. 416 p.
    Part 5 deals with physics apparatus.
90. UNESCO. *Unesco source book for science teaching*. Revised and enlarged edition. Paris, 1962. 250 p.
    This is Unesco's best selling publication.
91. UNESCO. *New Unesco source book for science teaching*. Paris, 1973. 240 p. + appendixes and index.
    Prepared with the intention of bringing the *Unesco Source Book for Science Teaching* up to date, and of providing a broader coverage of the scientific material likely to be included in introductory science courses.
92. LOCKARD, J. David (Project director and administrator). *Guidebook to*

constructing inexpensive science teaching equipment. Reginald F. Melton (Guidebook director), College Park, Inexpensive Science Teaching Equipment Project, Science Teaching Center, University of Maryland, 1972. Vol. I: *Biology*, 288 p.; vol. II: *Chemistry*, 287 p.; vol. III: *Physics*, 318 p.

93. EDUCATION DEVELOPMENT CENTER. *Annual report 1973.* 55 Chapel St., Newton, MA 02160 (United States).

94. UNESCO. *Bibliography on the development of science and mathematics concepts in children in African countries.* Paris.

    This photographic reproduction of an original manuscript is probably available from Unesco while the supply lasts. It covers the areas of psychology, science and mathematics.

95. PIAGET, Jean. Physical world of the child. *Physics today*, vol. 25, June 1972, p. 23-7.

    This issue of *Physics Today* was devoted to 'Physics for Children'. Note also articles by R. Karplus, 'Physics for Beginners', p. 36-47, and by J. Griffith and P. Morrison, 'Reflections on a Decade of Gradeschool Science', p. 29-34. The references to Piaget's work are so numerous that a beginner would do well to look first into a book *about* Piaget such as R. M. Beard, *An Outline of Piaget's Developmental Psychology for Students and Teachers*, London, Routledge & Kegan Paul, 1969.

96. FISHBACK, Woodson W. Early childhood education. *Illinois education*, January 1969, p. 189-91.

    Fishback cites Bloom's estimate of growth in children.

97. ROWE, Mary Budd. *Science and fate control.* A paper prepared for Section III-C of the meeting on 'Science and Man in the Americas' jointly sponsored by AAAS and CONACYT (see earlier under item 62).

    A copy of this paper may be available from the author at the Institute for Development of Human Resources, Department of Child Education, University of Florida, Gainesville, FL 32601 (United States). She says: 'Probably the single greatest contribution which early education in science can make to a people is the development of a sense of fate control, that is, the development of a belief, based on evidence, that one can to some extent influence the direction and quality of his destiny.'

98. UNITED NATIONS. *World plan of action for the application of science and technology to development.* New York, 1971.

    A document prepared by the Advisory Committee on the Application of Science and Technology for Development for the Second United Nations Development Decade. It contains a list of priority areas and proposals for implementing and financing the World Plan of Action. It also contains detailed proposals in selected areas.

99. UNITED NATIONS. *Science and technology for development.* New York, 1970.

    Contains proposals for the Second United Nations Development Decade prepared by the Advisory Committee on the Application of Science and Technology to Development.

100. UNITED NATIONS ECONOMIC AND SOCIAL COUNCIL. *Questions relating to science and technology: science education.* New York, 1968. (Doc. E/4814.)

101. RAMAKRISHNA, S.; SESHAMANI, R. *Science education in developing countries.* Bangalore, Indian Institute of Science, December 1973. 47 p.

This report was written for the Committee on Science and Technology in Developing Countries (COSTED) of the International Council of Scientific Unions (ICSU).

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